CONTRACT NAS 8-18037

ANALYTICAL STUDY OF NONMETALLIC PARTS FOR LAUNCH VEHICLES AND SPACECRAFT STRUCTURES

Quarterly Progress Report Number 3

Covering Period

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Prepared by

THE BOEING COMPANY

Space Division

Seattle, Washington

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Prepared for

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George C. Marshall Space Flight Center

Huntsville, Alabama

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FOREWORD

This report presents work accomplished by The Boeing Company during the third quarter January 1, 1967 to April 1, 1967 on an "Analytical Study of Nonmetallic Parts for Launch Vehicles and Spacecraft Structures", NASA Contract NAS 8-18037. Also included is a summarization of work accomplished during the first six months of the program which was previously reported in Quarterly Progress Reports #1 and #2. The work is administered by the George C. Marshall Space Flight Center, P&VE Laboratory, Huntsville, Alabama. The NASA Technical Leader is Mr. Carl A. Loy.

Performance of this contract is under the direction of the Structural Development Unit, Spacecraft Mechanics and Materials Technology, Space Division of the Boeing Company. Mr. C. F. Tiffany is Program Supervisor and Mr. D. H. Bartlett is Program Leader.

NOTE

Because this is a progress report, information contained herein is tentative and subject to changes, corrections, and modifications.

1.0 INTRODUCTION

The objective of this investigation is to determine the applicability of fiberglass reinforced plastics in spacecraft and launch vehicle structural components, with particular interest in the use of this type of structure to support cryogenic tanks. An additional objective is to compare the merit of these components with metallic parts of the same functional design. A survey of literature from past and current programs will be made to assemble information such as properties and methods of fabrication essential to the design phase. Parts will be designed utilizing the inherent advantages of reinforced plastic structure and comparisons made with designs of metallic parts. A quantity of parts will be fabricated and subjected to destruction tests intended to prove their suitability for the application selected.

During the first quarterly reporting period (July 1 to October 1, 1966) a literature survey was completed, structural composite properties were selected for design and three types of structural elements were chosen for design, fabrication and test. The structural elements selected were (1) tension members for cryogenic tank supports, (2) combined compression and tension struts for cryogenic tank supports, and (3) beams for payload packages (noncryogenic). Two tension rod configurations were selected for study; these were flat members with laminated metal foils for increased bearing strength, and round members incorporating a wedging feature at the end attachments. Compression struts in the length range of 20 to 30 inches were configured as cylindrical tubes of reinforced plastic construction bonded to metallic end fittings. It was found that significant weight savings in fiberglass compression struts are available when compared with metallic parts, if high loading is considered, i.e., 10,000 lbs or more for a 20 inch member; however, in any load range, the fiberglass parts consistently provide the least heat leak due to the low thermal conductivity of the composite. Beams with sandwich web, stiffened web and truss webs were investigated and the sandwich web approach was selected as providing the least weight design in the span lengths of interest.

The reinforcement selected for all designs was S-994 fiberglass in either multiple end rovings, cloth or single end yarn. A variety of acceptable resin systems were identified in the literature survey, the preferred being Epon 826 (for wet winding) and E-787 prepreg. Structural composite properties for design were selected from results of the Reference 1 contract.

A detailed presentation of study results and a discussion of the analytical approach is contained in the first Quarterly Report.

During the second quarterly reporting period (October 1, 1966 to January 1, 1967) the detailed design of flat and round tension rods and a compression strut were developed. A titanium tension rod and a titanium compression strut were also designed using the same loads as for the nonmetallic parts to allow heat flow comparisons. The beam optimization computer program was initiated and produced data on cross section geometry and weight for a variety of spans and loading.

In addition the test plans for tension rods and compression struts were prepared and coordinated with the MSFC Technical Monitor and material orders were placed for fiberglass, epoxy resin, adhesives, and the required metallic materials. The manufacturing methods were selected and tool design started. The analysis of aluminum beams was completed. Comparisons of the two types of beams with equal loading showed that fiberglass offered the least weight structure for spans of 20", 40", and 60". The aluminum beam was the least weight for the 80" span.

A detailed explanation of study results and a discussion of the analytical approach is contained in the second Quarterly Progress Report.

2.0 SUMMARY OF WORK ACCOMPLISHED

During the seventh month, materials for fabrication of tension rods and compression struts were received and the machining of winding mandrels and compression strut end caps was initiated. A control specimen test plan was prepared and 1/2" lap bond tests with Narmco 7343/7139 adhesive were made to verify selection of the end cap lap length. The bond strengths exhibited were below design requirements so testing of longer lap lengths was planned for the eighth month.

The beam optimization computer program was completed and a beam size selected for fabrication and test. A 60 inch member was chosen because this was the longest span showing a weight advantage for fiberglass. A 12 inch depth was selected which resulted in a beam that would support approximately 17,000 pounds.

During the eighth month, fabrication of winding mandrels for compression struts, round tension rods, and flat tension rods were completed. Tool tryout of the compression tube mandrel was initiated by winding a part from surplus "E" glass.

Lap bond tests with Narmco 7343/7139 were completed by testing 3/4" and 1" lap lengths. The strength derived from the 1" lap satisfied design requirements, subsequently the strut drawing was changed to increase the end fitting bond length from 1/2" to 1".

The fiberglass beam design was completed and the materials for fabrication were ordered. The materials selected were U. S. Polymeric 181 "S" glass cloth for the web skins and 20 end roving for the flanges. Hexcel 3/16 HRP honeycomb core was chosen for stabilizing the web skins. The glass cloth and roving were to be preimpregnated with E-787 resin by the supplier.

During the ninth month a portion of the materials preliminary tests were completed. These were (1) the resin hardness and heat distortion tests,

(2) glass area determination, (3) tensile strength of processed 12 end roving and single end yarns, and (4) resin content of impregnated 12 end roving and single end yarns.

Four compression tubes were fabricated in the ninth month. Three of these were acceptable and one was destroyed while being removed from the mandrel, as was the first part, made during the eighthmonth. Machining of aluminum end caps was completed and the spherical bearings were swaged in place.

Forming of the curved foils for the round tension rods was started, however, the small radii and stiffness of the full hard stainless steel have caused problems. A special form die is being made to alleviate the problem. Lap shear tensile specimens are being made to determine foil to laminate bond strength. The strength data from these specimens will be used in finalizing the designs of flat and round tension rods.

The manufacturing and assembly procedures for fabricating the composite beam were selected and tool design was initiated.

A more detailed discussion of accomplishments follows:

<u>Material Evaluation Tests</u>

Compression struts and tension rods are fabricated by a wet winding process, using "S" glass in 12 end and single end yarns and Epon 826 epoxy resin. Certain materials tests are required to determine the effectiveness of process controls and the basic material strength for finalizing the designs. These preliminary materials tests were defined in Table I of the Fifth monthly progress report. The same table (Table II) is shown in this report with the results of some of the tests.

The tensile strength of impregnated and cured yarns and rovings was lower than

		Resin	Single End Yarn	12 end Roving	Epoxy Phenolic Adhesive (BMS 8-30)	Polyurethane Adhesive (Narmco 7343/7139)	Impregnated Single end Yarn	Impregnated 12 end Roving
Preliminary Tests	Heat Distortion	273°F AVG						
	Hardness	Shore Durometer D89						
	Glass Area		2.066×10^{-5} in^2	2.538×10^{-4} in^2				
	Tensile Strength (NOL rings)						Tests not completed	Tests not completed
	Tensile Strength ("straws")						398,[illegible]00 psi AVG. glass stress	363.100 psi AVG. glass stress
	Resin content						18.67%	18.[illegible]%
	Lap Bond Strength (Glass lam. to 2024)					See Fig. 2		
	Lap Bond Strength (Glass lam. to 301 cres.)				Tests not completed			

TABLE 1

anticipated and has necessitated more tensile testing to determine if the purchased material or impregnating and spooling processes are the cause. The strengths shown in the table are known to be substandard by comparison with typical strengths obtained in References 2 and 3. These reference reports give details on specimen preparation and test methods for single and multiple end yarns and include strength data, commonly used as a standard at Boeing.

The fabrication procedures used in winding compression tubes and the round tension rods requires hand placement of the longitudinal filaments. This method has been selected in lieu of mechanized longitudinal winding to minimize costs. It was necessary to "prepreg" quantities of material and store this material on spools for later use, since it is nearly impossible to maintain resin content control by pulling the yarns through the impregnator, shown in Figure 1, and winding directly onto the mandrel. It is possible that the impregnating and respooling process is responsible for the reduction in strength. Additional tensile specimens are being prepared to determine (1) the "as received" glass strength, (2) the impregnated but not respooled glass strength, and (3) the effect of increased resin content on glass strength.

Three acceptable compression tubes have been made with respooled material and it is planned to continue with the same processing to assure timely completion of the program. This approach should have no adverse effect on compression tube load capacity since the elastic modulus is expected to be unaffected by the processing and the fiberglass is worked to less than 30,000 psi in compression or tension at design ultimate load. However, low stress levels are not the case with tension rods, and a more thorough knowledge of the purchased material and the effect of processing on material strength is required before finalizing the design or fabrication procedures.

Resin content of the impregnated and respooled material has been determined

RESEARCH - IMPREGNATING EQUIP. 2A221246
1-3-66

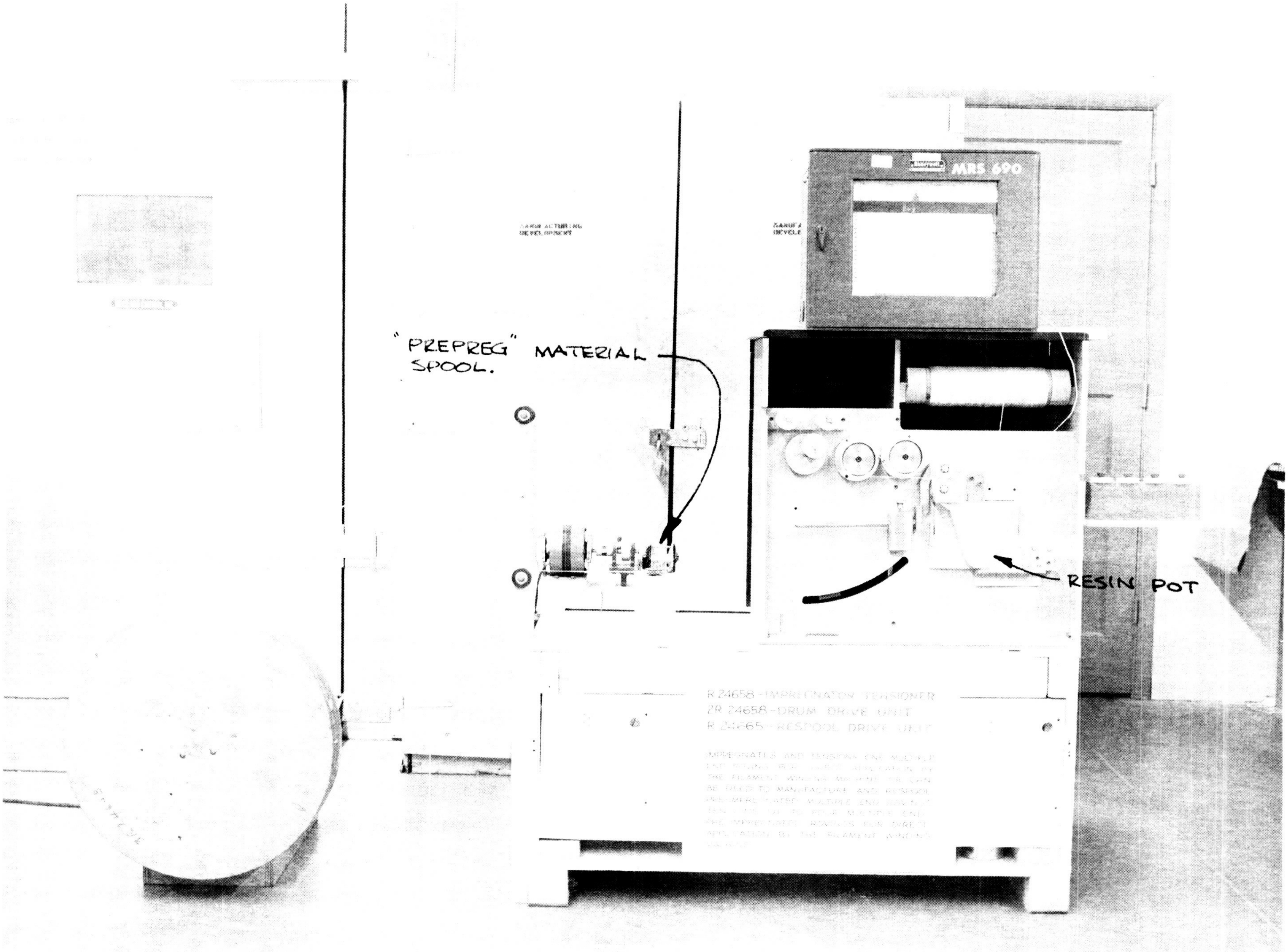


FIGURE 1

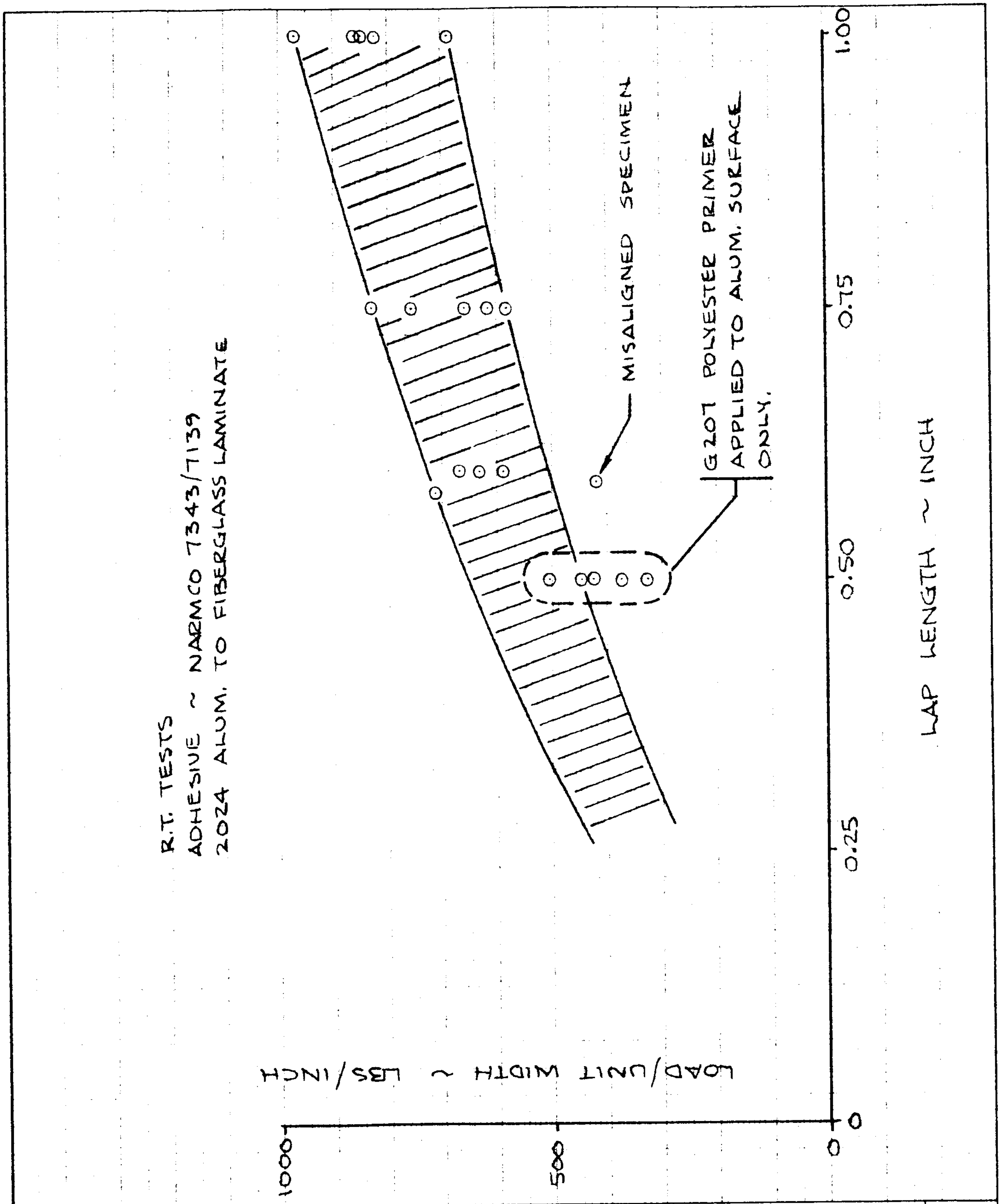
and is within the tolerance specified on the drawing for the finished parts. Resin content control in the winding material is essential to achieving the required content in the parts since no resin is added or removed during winding.

Resin tests are complete and both the material and cure cycle are acceptable. Hardness tests were conducted in accordance with ASTM D 1706-61 using an instant reading on a Shore D Durometer. An individual reading was made on each of five separate resin castings. All castings had a hardness of Shore D89 which is well above the minimum value of 80 required for a fully cured casting. Heat deflection tests were conducted in accordance with ASTM D 648-56 at a flexural stress of 264 psi on the 1/2 x 1/2 x 5 inch cast bars. The temperatures required to produce the standard deflection are tabulated below for the five bars tested.

	276°F
	274
	272
	270
	274
AVG	273°F

The minimum acceptable temperature for EPON 826/MNA/BDMA is 250°F.

Lap bond testing of aluminum to fiberglass laminate with Narmco 7343/7139 adhesive is complete and the results of 20 specimen tests are shown in Figure 2. These tests were conducted to determine the correct lap length for bonding aluminum end caps to the fiberglass compression tubes. The design ultimate load in this bond is approximately 540 pounds/lineal inch of joint. The test data shows a large variation in strengths for each lap length tested and since this joint should have an ample margin of safety. the 1.00 inch lap length was selected for the design. Visual inspection of the failed specimens showed that the adhesive did not adhere to the aluminum in all cases with the exception of those specimens prepared with G-207 primer. The latter specimens



	INITIALS	DATE	REV BY INITIALS	DATE	TITLE	MODEL
CALC					TENSILE LAP SHEAR TEST DATA	
CHECK						
APPD.						
APPD						

U3 4013 8000 REV. 12-64

REV LTR

BOEING | NO. FIGURE 2

SH

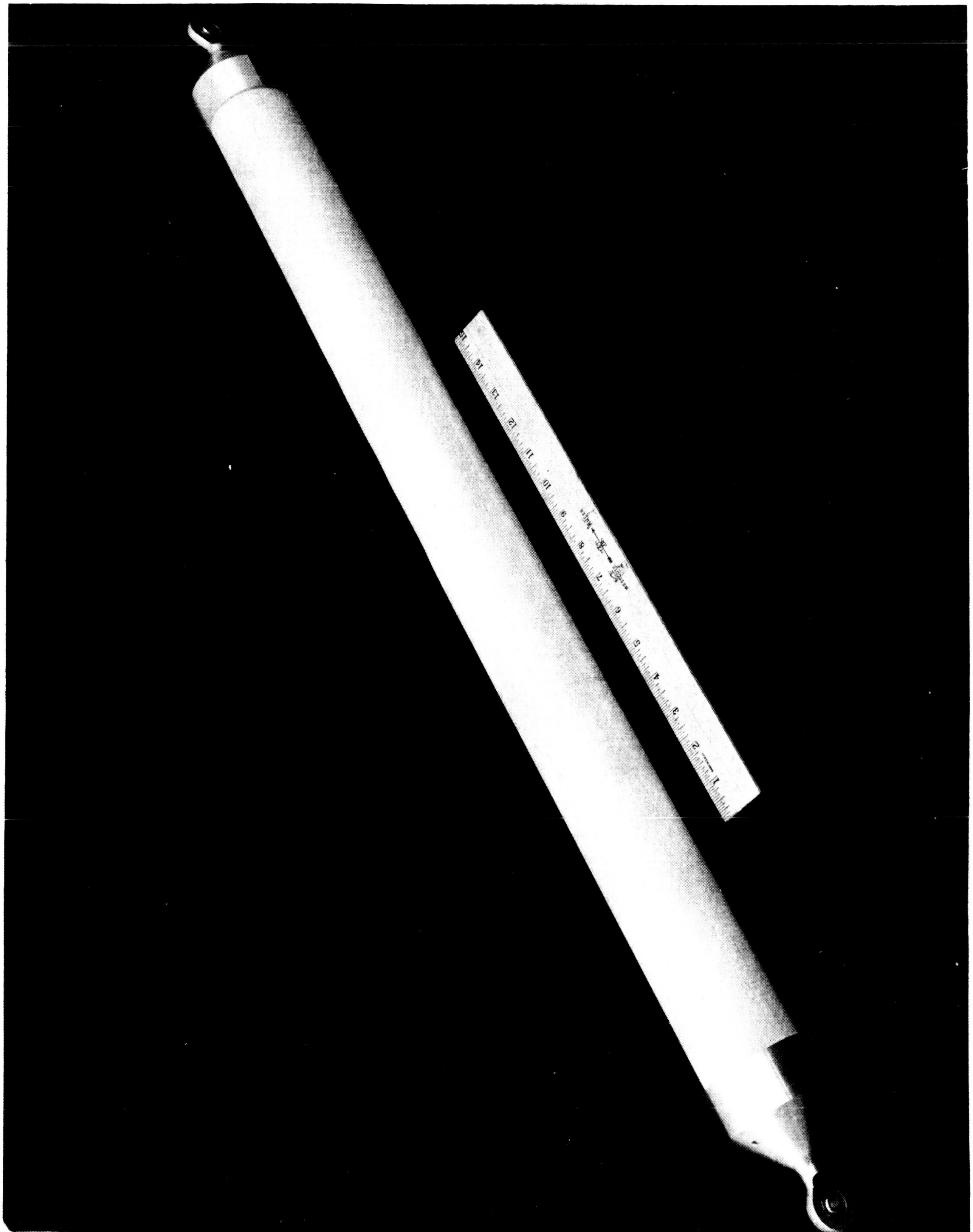
consistently failed along the laminate to adhesive bond line, with some evidence of glass fibers adhering to the adhesive.

Compression Struts

During the third quarterly reporting period the compression tube mandrel concept was developed and a total of five parts were fabricated. Of these five parts, the first two were destroyed because of release agent failure. A photograph of the first failed part is shown in Figure 3. The mandrel is a smooth cylindrical aluminum tube which was covered with a one mil teflon film heat sealed in place, prior to winding the part. After winding and curing, machine cuts were made to produce the required length. The end trim material was removed from the mandrel and the tube was then pushed off with a metal sleeve. The tube moved freely except for the last 6 inches which became wedged onto the mandrel because the parting film wrinkled and folded. Subsequent efforts to remove the part failed and the end of the tube was cut as shown in the photograph. A silicone spray parting film was used for the second tube; however, it was impossible to move this part by sliding. Liquid nitrogen cold shocking of the mandrel was employed and, although there was visible evidence of separation between the mandrel and the part, they remained locked together. It was necessary to cut the second part to remove it from the mandrel. Inspection revealed numerous scratches and slight evidence of machining grooves on the mandrel which were subsequently removed by hand polishing. The mandrel was then dispersion coated with teflon and the coating was sintered to provide a complete film without joints. The third, fourth, and fifth tubes were wound and successfully removed after cold shock. Figures 4, 5, and 6 show the fiberglass tube and the aluminum end fittings.

A plot of fiberglass strut heat flow versus strut diameter was included as Figure 5 in the Second Quarterly Progress Report. The purpose of this curve was to provide a comparison between fiberglass and titanium for the strut

FIGURE 3



RESEARCH SUPPORT. ORIENTED FILAMENT TANK 3 3-67 2A245313

FIGURE 4

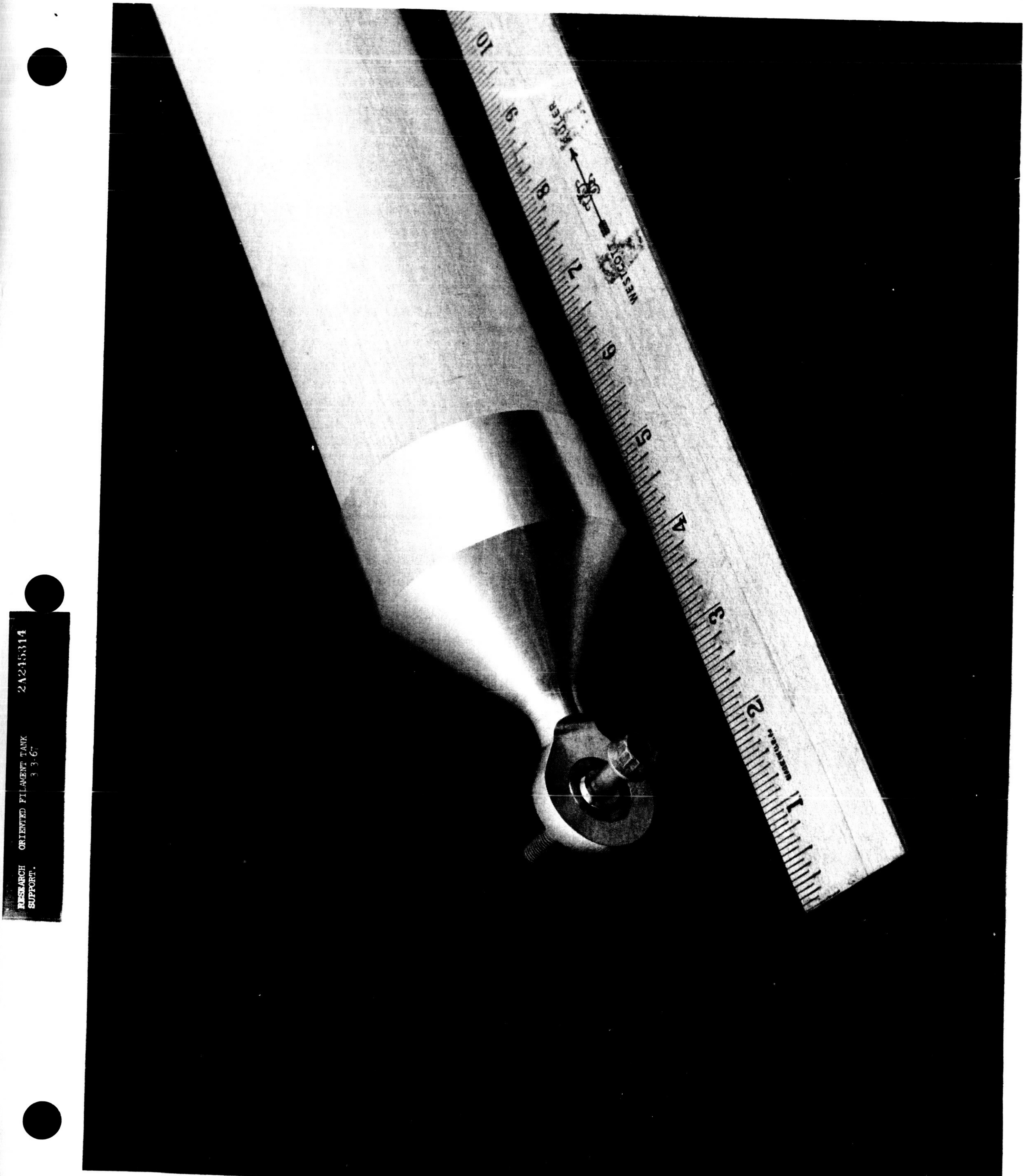

RESEARCH SUPPORT.
ORIENTED FILAMENT TANK
3-3-67
2A245314
WESTCOTT

FIGURE 5

RESEARCH ORIENTED FILAMENT TANK SUPPORT. 3-3 67 2A245312

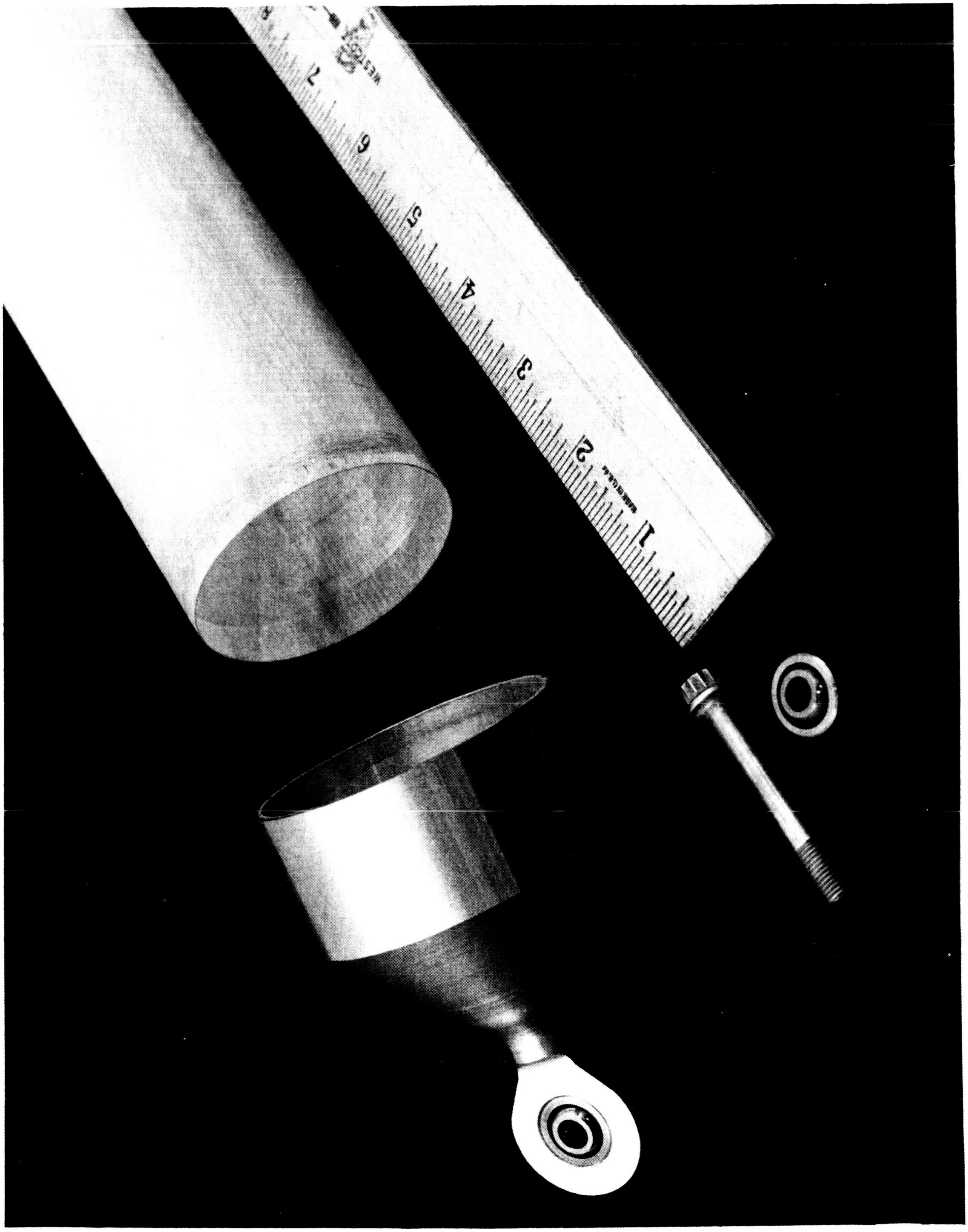


FIGURE 6

material and to show the heat flow penalties incurred if a nonoptimum fiberglass tube diameter is chosen. It has been found that the data related to the fiberglass parts are in error due to use of the wrong thermal conductivity value. The thermal conductivity data listed in the Reference 1 report was used, however, the wrong mean value was selected. The correct value appears to be .013 BTU-IN/IN^2-HR-°F, or approximately one-half the conductivity used in constructing the curve. The correct value compares reasonably well with data from the Reference 4 report. A revised curve of strut heat flow has been prepared and is shown in Figure 7.

Beams

The beam design has been completed and submitted to the MSFC technical monitor for comment. The design drawing of this beam is shown in Figure 8. The 60-inch length was selected for fabrication because this was the longest span showing a weight advantage for fiberglass as evidenced by Figure 9. Two points are shown on these curves which represent the aluminum and fiberglass beams selected for design. The point for the fiberglass beam falls above the curve due largely to the addition of a layer of fiberglass cloth on the inner face of both flanges to aid in shear distribution from the web to the unidirectional filaments. This additional layer was not considered in the original analysis. The design drawing of the aluminum beam has not been included since it is not completed.

The twelve inch beam depth was selected arbitrarily. Figure 10 is a plot of beam element geometry from the computer optimization for the 60-inch span. For a 12 inch depth, it appears that the beam load capacity is 14,900 pounds, however, the configuration selected for design did not represent a specific point in the analysis. As a result, an additional computer analysis was made for the 12-inch depth and it was found that the beam had a load capacity of 17,000 pounds in the form of two 8,500 pound loads at span 1/3 points. To achieve this load capacity, the compression flange must be laterally supported

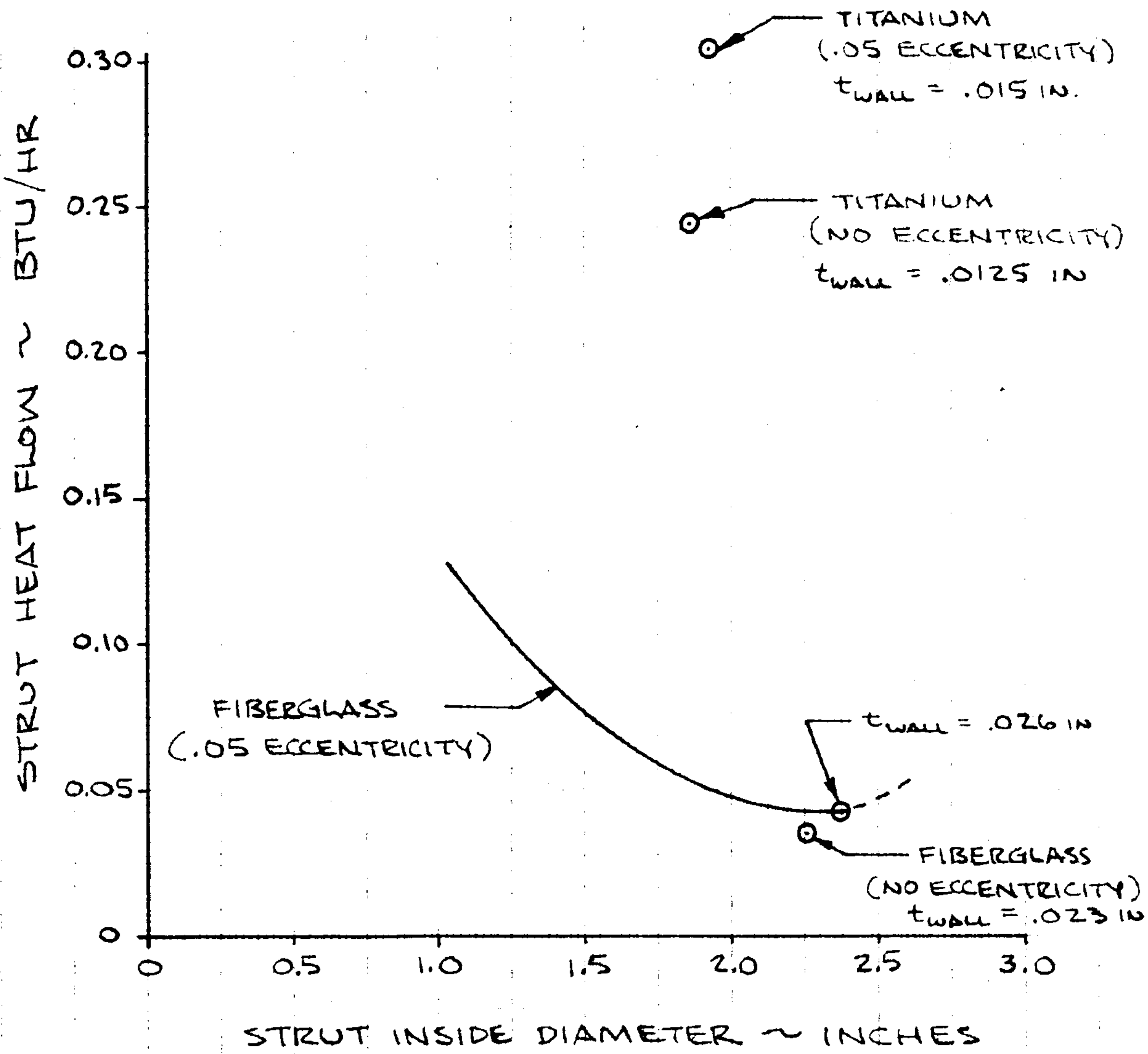
COLUMN LENGTH BETW. CTRS. = 36 INCH
COLUMN LOAD = ± 4000 LB (ULTIMATE)

FIBERGLASS STRUT

S-994 GLASS E-787 RESIN - BFW
$E = 5\times10^6$ psi $K = .013 \frac{BTU-IN}{IN^2-HR-°F}$

TITANIUM STRUT

6AL-4V ALLOY
$E = 16\times10^6$ psi $K = .24 \frac{BTU-IN}{IN^2-HR-°F}$



	INITIALS	DATE	REV BY INITIALS	DATE	TITLE	MODEL
CALC					EFFECT OF STRUT MATERIAL AND DIAMETER ON HEAT FLOW	
CHECK						
APPD						
APPD						

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REV LTR

BOEING NO. FIGURE 7

SH

	QTY REQD	PART OR IDENTIFYING NUMBER	NOMENCLATURE OR DESCRIPTION	ZONE	MATERIAL AND SPECIFICATION	HT TR	FINISH	PT MK	REV LTR
	6	MS27183-7	WASHER						
✓	8	NAS679C3W	NUT						
✓	8	AN3C-15A	BOLT						
✓	8	-8	RADIUS FILLER		2024-T4 AL PER QQ-A-250/4 [illegible] PER QQ-A-250/12				R
✓	8	-7	BRACKET		MAKE FROM [illegible] [illegible] QQ-A-250/[illegible] 250/12				2
-2	8	-6	BRACKET DOUBLER		2 3	5			
-2	2	-5	COMPOSITE FLANGE		2 3 3	5			
-2	2	-4	COMPOSITE FACE SKIN		2 3	5			
-2	1	-3	WEB CORE		1				
✓	1	-2	BEAM ASSY OF		ASSY PER 6 7 8 9 10 11	5			
—	—	-1	FIBERGLASS BEAM ASSY		ASSEMBLY PER 6 7 8	6			
-1									

LIST OF MATERIAL

PART MARKING PER BAC 5307
RIVET INST & SYMBOLS PER BAC 5004
SEE BACD 2097 FOR SURFACE ROUGHNESS
FORM, PUNCH, STRAIGHTEN & FIT
METAL PARTS PER BAC 5300
BOLT & NUT INSTALLATION PER BAC 5009
MATERIAL SUBSTITUTION & EQUIVALENTS PER BAC 5105
FOR FINISH CODE SEE DOC D2 5000

VENDOR ITEM SEE SOURCE CONTROL OR SPECIFICATION CONTROL DRAWING

DWG ORIG BY (GROUP) CHANGE NO.

DIMENSIONING & TOLERANCING PER MIL STD-8
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES
ANGLES $\pm \frac{1}{2}°$ DECIMALS $\pm$.[illegible]
RIVET & BOLT EDGE MARGINS $\pm$.05
BEND RADII
$\pm$.01 ON .03 & .36
$\pm$.03 ON .09 & GREATER
SHEET METAL CORNER RADII
INT $\frac{19}{16}$ EXT $\frac{21}{30}$

CNTR NAS8-15037
STRUCT. DEVELOPMENT

THE BOEING COMPANY
AERO SPACE DIVISION SEATTLE, WASHINGTON

BEAM ASSEMBLY— FIBERGLASS REINFORCED PLASTIC

SIZE J
CODE IDENT NO 81205
SK11-039925
SCALE SH 1 OF 1

SK11-039925 SHEET 1/1

FIGURE 8

.625

1 FIBERGLASS CORE, HRP, 3/16" GF 11-4.0 LB/FT^3
HEXCEL PRODUCTS INC., 2332 4TH ST, BERKELEY, CALIF.

2 STYLE 181 S/901 FIBERGLASS CLOTH IN U.S. POLYMERIC E-787 PREPREG FORM
U.S. POLYMERIC CHEMICALS CO. INC., 700 EAST DYER ROAD, SANTA ANA, CALIF.

3 UNIDIRECTIONAL FILAMENT WOUND 20 END S/901 FIBERGLASS IN U.S. POLYMERIC E-787 PREPREG. FORM.
U.S. POLYMERIC CHEMICALS CO. INC., 700 EAST DYER ROAD, SANTA ANA, CALIF.

4 CURE 24 HRS @ 80°F PLUS 5 HRS @ 125°F. DO NOT ALLOW POTTING COMPOUND TO PROTRUDE ABOVE CORE SURFACE.

5 LAMINATE -4 (INCLUDING -6 DOUBLERS) FACE SKINS AND -5 FLANGES BY THE POSITIVE PRESSURE MOLDING PROCESS AS DESCRIBED IN BAC 5456.
1. LAMINATING MATERIALS PER 2 AND 3.
PARTING AGENTS PER SECT. 3.4.
MISC. MATERIALS PER SECT. 3.5.
2. PREPARE MOLDING SURFACES PER SECT. 4.2.
3. APPLY PARTING FILM PER SECT. 4.3.
4. LAYUP LAMINATE LAYERS PER DRAWING. ATTENTION SHOULD BE GIVEN TO ARRANGEMENT OF WARP AND FILL FOR EACH LAYER.
NO SEAMS WILL BE ALLOWED IN ANY PLY EXCEPT AS NOTED ON THE DRAWING.
5. VACUUM BAG AND CURE UNDER 50 PSI AUTOCLAVE PRESSURE FOR 4 HRS @ 325°F.
6. MACHINE FINISH EDGES PER SECTION 4.9. EXCEPT GLASS CLOTH LAYER MAY ENCIRCLE -5 FLANGE SHOWN IN DETAIL I.

6 THE FOLLOWING SECTIONS OF BAC 5450 ARE APPLICABLE:
1. HANDLE CLEANED PARTS PER SECT. 5450.413.
2. APPLY ADHESIVE PER SECT. 5450.451.
3. CURE PER SECT. 5450.481.
4. CURING PRESSURE PER SECT. 5450.482. PRESSURE TO BE 10 - 100 PSI.
5. CURING TEMPERATURES PER SECT. 5450.483 (325 - 350°F FOR 45 MIN.)
FURNACE CURE CYCLE RECORDS ARE REQUIRED.

7 CLEAN ALUMINUM SURFACES TO BE BONDED AS FOLLOWS:
1. HYDROBLAST
2. CLEAN IN A SOLUTION OF SULFURIC ACID AND SODIUM DICHROMATE PER BAC 5765 METHOD 2.
CLEAN FIBERGLASS LAMINATE SURFACE TO BE BONDED AS FOLLOWS:
1. WIPE WITH MEK.
2. SAND WITH 320 ABRASIVE PAPER TO REMOVE GLOSS.
3. WIPE WITH MEK AND AIR DRY.

PREPREG CLOTH)

8 CLEAN FIBERGLASS LAMINATE SURFACE TO BE BONDED AS FOLLOWS:
1. WIPE WITH MEK.
2. SAND WITH 320 ABRASIVE PAPER TO REMOVE GLOSS.
3. WIPE WITH MEK AND AIR DRY.

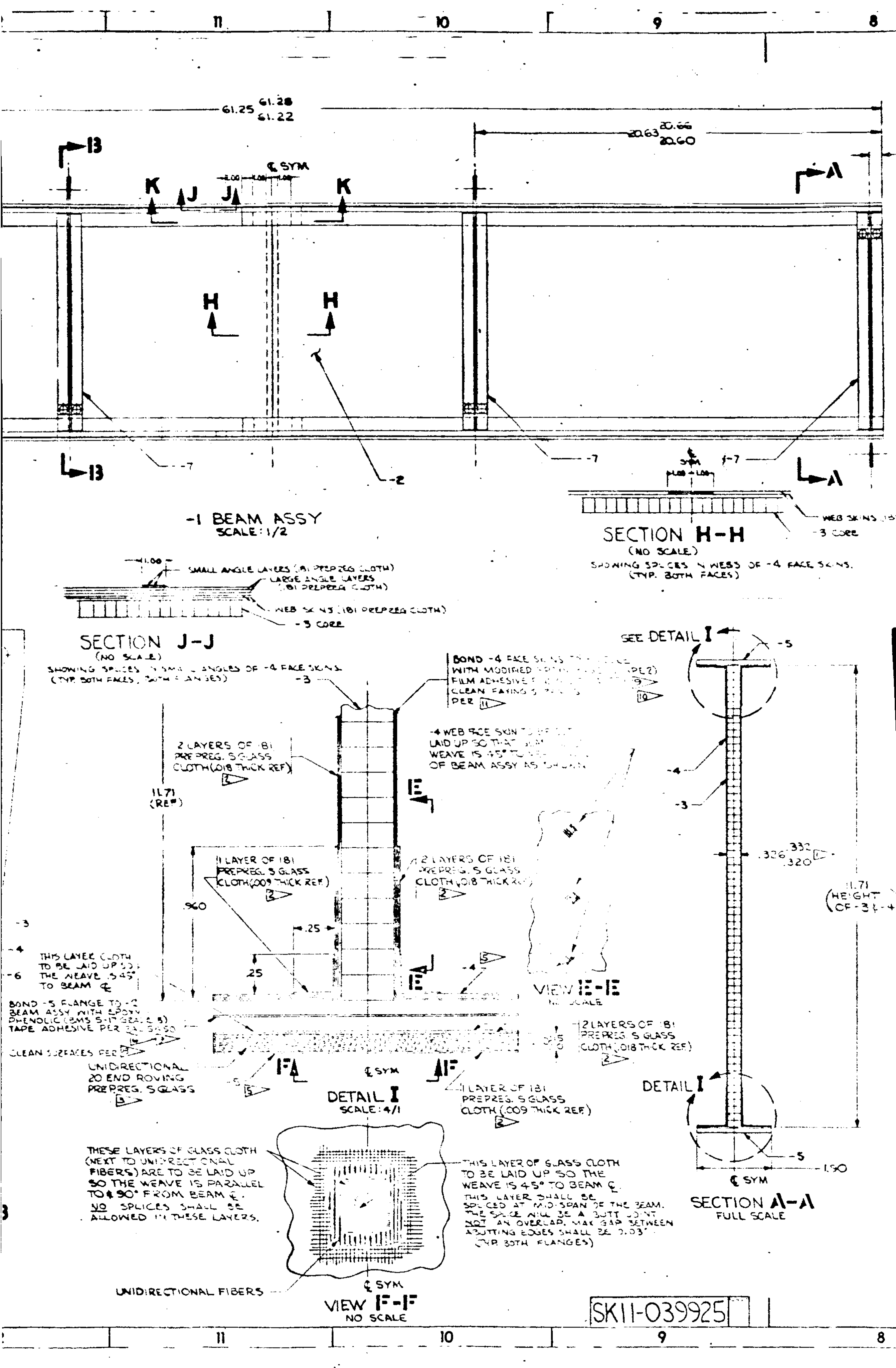
9 DURING ALL BONDING OPERATIONS (-4 TO -3; -5 TO -2; AND -7 TO -1) UNIFORM PRESSURE AND HEAT MUST BE MAINTAINED OVER ENTIRE PART TO AVOID WARPAGE

10 THE FOLLOWING SECTIONS OF BAC 5514-551 ARE APPLICABLE:
1. MATERIALS CONTROL PER SECT. 4.0.
2. CLEANLINESS REQUIREMENTS PER SECT. 7.5.
3. ADHESIVE APPLICATION PER SECT. 7.5.4, EXCEPT USE OF POSITIONING FABRIC PER 7.5.4.1 WILL NOT BE ALLOWED.
4. GENERAL CURING REQUIREMENTS PER SECT. 7.9.1.
5. CURE TEMPERATURE REQUIREMENTS PER SECT. 7.9.2. (225-250°F FOR 90 MIN.)
6. CURE PRESSURE REQUIREMENTS PER SECT. 7.9.3 (25 - 100 PSI)
7. ADHESIVE CONTROL PER SECT. 8.1.1 AND 8.2.3.

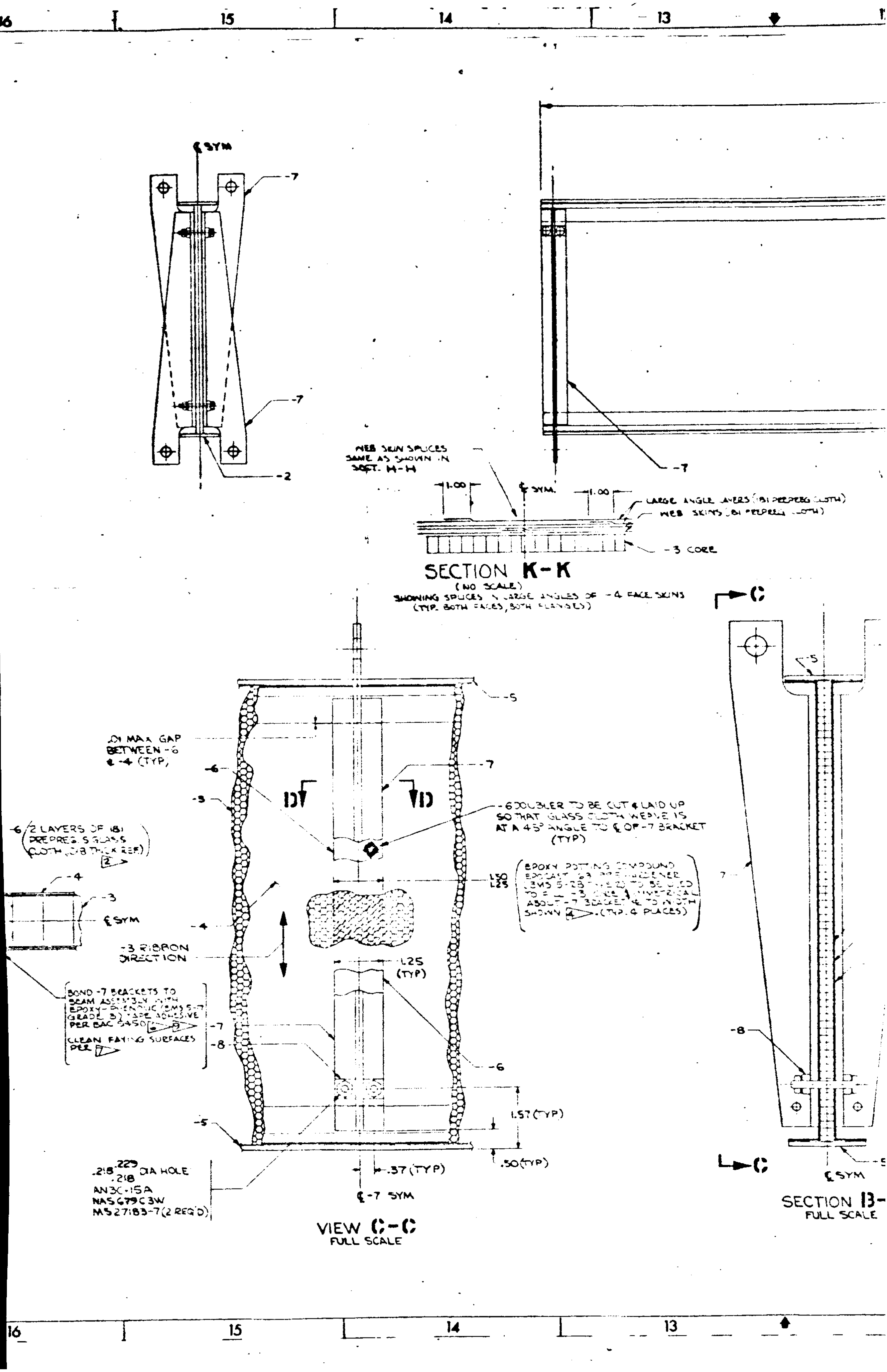
11 CLEAN HRP -3 HONEYCOMB CORE AS FOLLOWS:
1. CLEAN FAYING SURFACES BY SANDING WITH 150 ABRASIVE PAPER.
2. CLEAN ENTIRE CORE BY VAPOR DEGREASING WITH TRICHLOROETHYLENE (PER BAC 5408). EXPOSURE TO TRICHLOR. SHALL BE MINIMIZED (60 SECONDS MAX.) TO AVOID SOFTENING.
CLEAN FAYING SURFACES OF -4 FACE SKINS AS FOLLOWS:
1. WIPE WITH MEK.
2. SAND WITH 320 ABRASIVE PAPER TO REMOVE GLOSS.
3. WIPE WITH MEK AND AIR DRY.

BASIC	RIVET	CODE

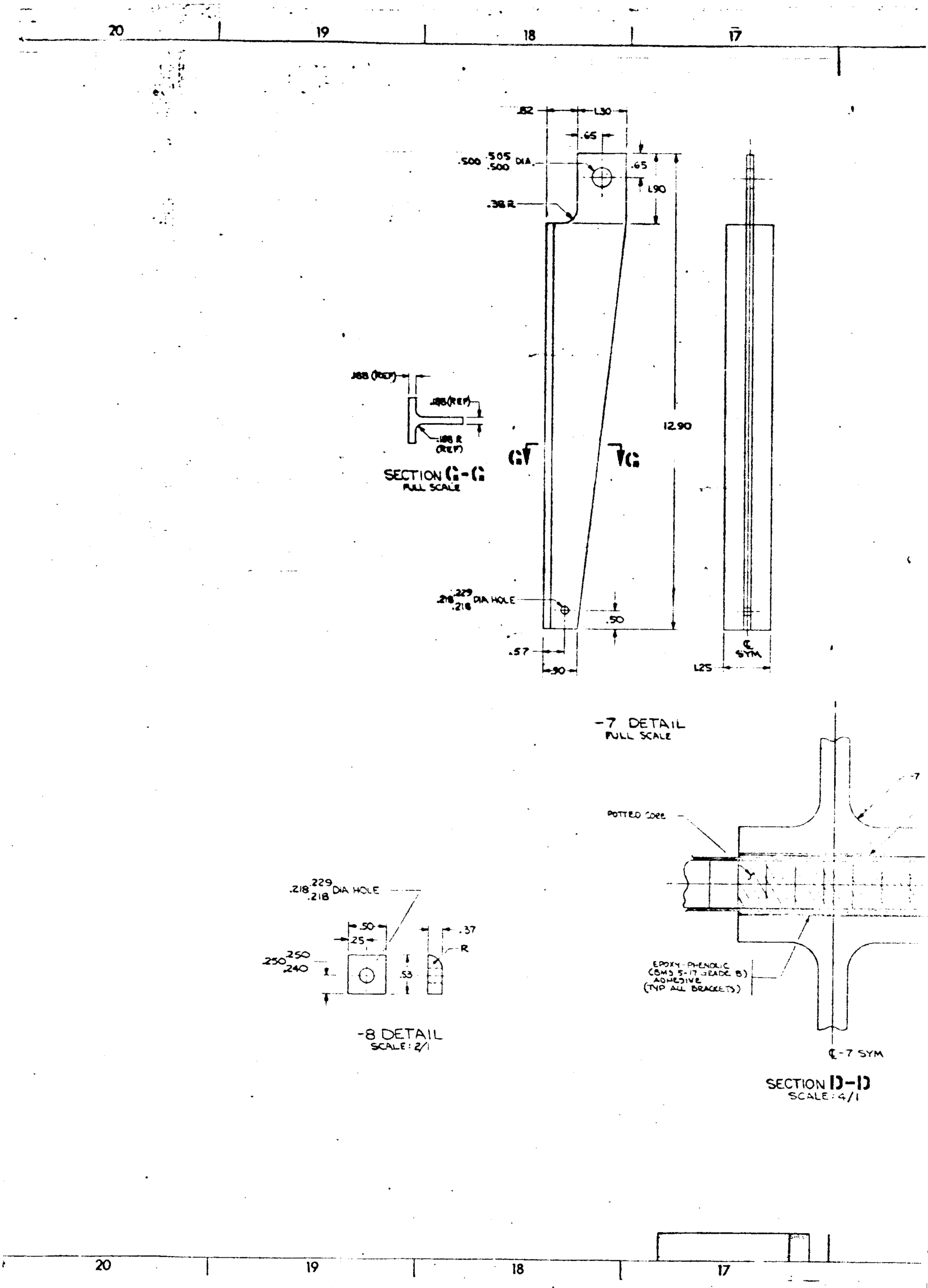
NEXT ASSY	USED ON	SECT NO	SERIAL NUMBER	PART NUMBER			REV LTR
APPLICATION							



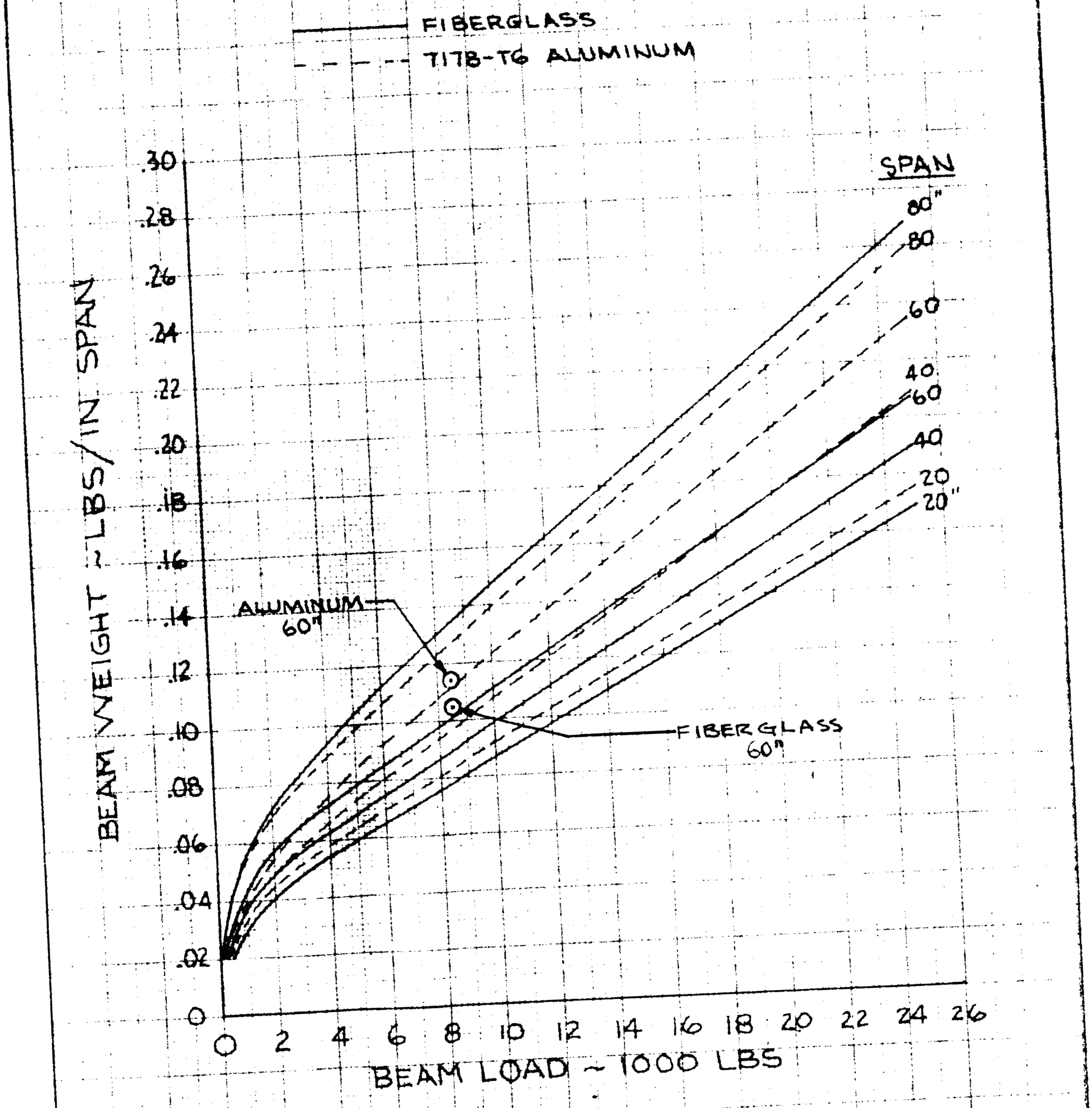
11
10
9
8
61.25
61.28
61.22
20.63
20.66
20.60
℄ SYM
B
A
K
J
H
-7
-2
-1 BEAM ASSY
SCALE: 1/2
SECTION H-H
(NO SCALE)
SHOWING SPLICES IN WEBS OF -4 FACE SKINS.
(TYP. BOTH FACES)
-3 CORE
1.00
SMALL ANGLE LAYERS (181 PREPREG CLOTH)
LARGE ANGLE LAYERS
(181 PREPREG CLOTH)
WEB SKINS (181 PREPREG CLOTH)
-3 CORE
SECTION J-J
(NO SCALE)
(TYP. BOTH FACES, BOTH FLANGES)
BOND -4 FACE SKINS
WITH MODIFIED
FILM ADHESIVE
CLEAN FAYING
PER
-4 WEB FACE SKIN
LAID UP SO THAT
WEAVE IS 45°
OF BEAM ASSY AS SHOWN
2 LAYERS OF 181
PREPREG. S GLASS
CLOTH (.018 THICK REF)
11.71
(REF)
1 LAYER OF 181
PREPREG. S GLASS
CLOTH (.009 THICK REF)
.960
.25
THIS LAYER CLOTH
TO BE LAID UP SO
THE WEAVE IS 45°
TO BEAM ℄
BOND -5 FLANGE TO -2
BEAM ASSY WITH EPOXY
PHENOLIC
TAPE ADHESIVE PER
CLEAN SURFACES PER
UNIDIRECTIONAL
20 END ROVING
PREPREG. S GLASS
F
E
VIEW E-E
2 LAYERS OF 181
PREPREG. S GLASS
CLOTH (.018 THICK REF)
DETAIL I
SCALE: 4/1
1 LAYER OF 181
PREPREG. S GLASS
CLOTH (.009 THICK REF)
SEE DETAIL I
-5
-4
-3
.326
.332
.320
11.71
HEIGHT
DETAIL I
1.90
℄ SYM
SECTION A-A
FULL SCALE
THESE LAYERS OF GLASS CLOTH
(NEXT TO UNIDIRECTIONAL
FIBERS) ARE TO BE LAID UP
SO THE WEAVE IS PARALLEL
TO & 90° FROM BEAM ℄.
NO SPLICES SHALL BE
ALLOWED IN THESE LAYERS.
THIS LAYER OF GLASS CLOTH
TO BE LAID UP SO THE
WEAVE IS 45° TO BEAM ℄.
THIS LAYER SHALL BE
SPLICED AT MID-SPAN OF THE BEAM.
THE SPLICE WILL BE A BUTT JOINT
NOT AN OVERLAP. MAX GAP BETWEEN
ABUTTING EDGES SHALL BE 0.03"
(TYP. BOTH FLANGES)
UNIDIRECTIONAL FIBERS
℄ SYM
VIEW F-F
NO SCALE
SK11-039925



16
15
14
13
℄ SYM
-7
-7
-2
WEB SKIN SPLICES SAME AS SHOWN IN SECT. H-H
1.00
℄ SYM.
1.00
LARGE ANGLE LAYERS (181 PREPREG CLOTH)
WEB SKINS (181 PREPREG CLOTH)
-3 CORE
SECTION K-K
(NO SCALE)
SHOWING SPLICES IN LARGE ANGLES OF -4 FACE SKINS
(TYP. BOTH FACES, BOTH FLANGES)
C
-5
.01 MAX GAP BETWEEN -6 & -4 (TYP)
-6
-7
-5
D
D
-6 DOUBLER TO BE CUT & LAID UP SO THAT GLASS CLOTH WEAVE IS AT A 45° ANGLE TO ℄ OF -7 BRACKET (TYP)
-6 (2 LAYERS OF 181 PREPREG S GLASS CLOTH .018 THICK REF) 2
-4
-3
℄ SYM
1.50
1.25
SHOWN 4 (TYP. 4 PLACES)
-4
-3 RIBBON DIRECTION
1.25 (TYP)
BOND -7 BRACKETS TO BEAM ASSEMBLY WITH
PER BAC 5450
CLEAN FAYING SURFACES PER 7
-7
-8
-6
-5
1.57 (TYP)
.50 (TYP)
$.218^{.229}_{.218}$ DIA HOLE
AN3C-15A
NAS679C3W
MS27183-7 (2 REQ'D)
.37 (TYP)
℄ -7 SYM
VIEW C-C
FULL SCALE
-5
7
-8
C
℄ SYM
SECTION B-
FULL SCALE
16
15
14
13



20
19
18
17
.82
1.30
.65
.500 .505 .500 DIA.
.65
1.90
.38 R
12.90
.188 (REF)
.188 (REF)
.188 R (REF)
SECTION G-G
FULL SCALE
.218 .229 .218 DIA HOLE
.50
.57
.90
℄ SYM
1.25
-7 DETAIL
FULL SCALE
POTTED CORE
-7
.218 .229 .218 DIA HOLE
.50
.25
.37
R
.250 .250 .240
.53
-8 DETAIL
SCALE: 2/1
EPOXY-PHENOLIC (BMS 5-17 GRADE B) ADHESIVE (TYP ALL BRACKETS)
℄-7 SYM
SECTION D-D
SCALE: 4/1



	INITIALS	DATE	REV BY INITIAL	DATE
CALC				
CHECK				
APPD.				
APPD.				

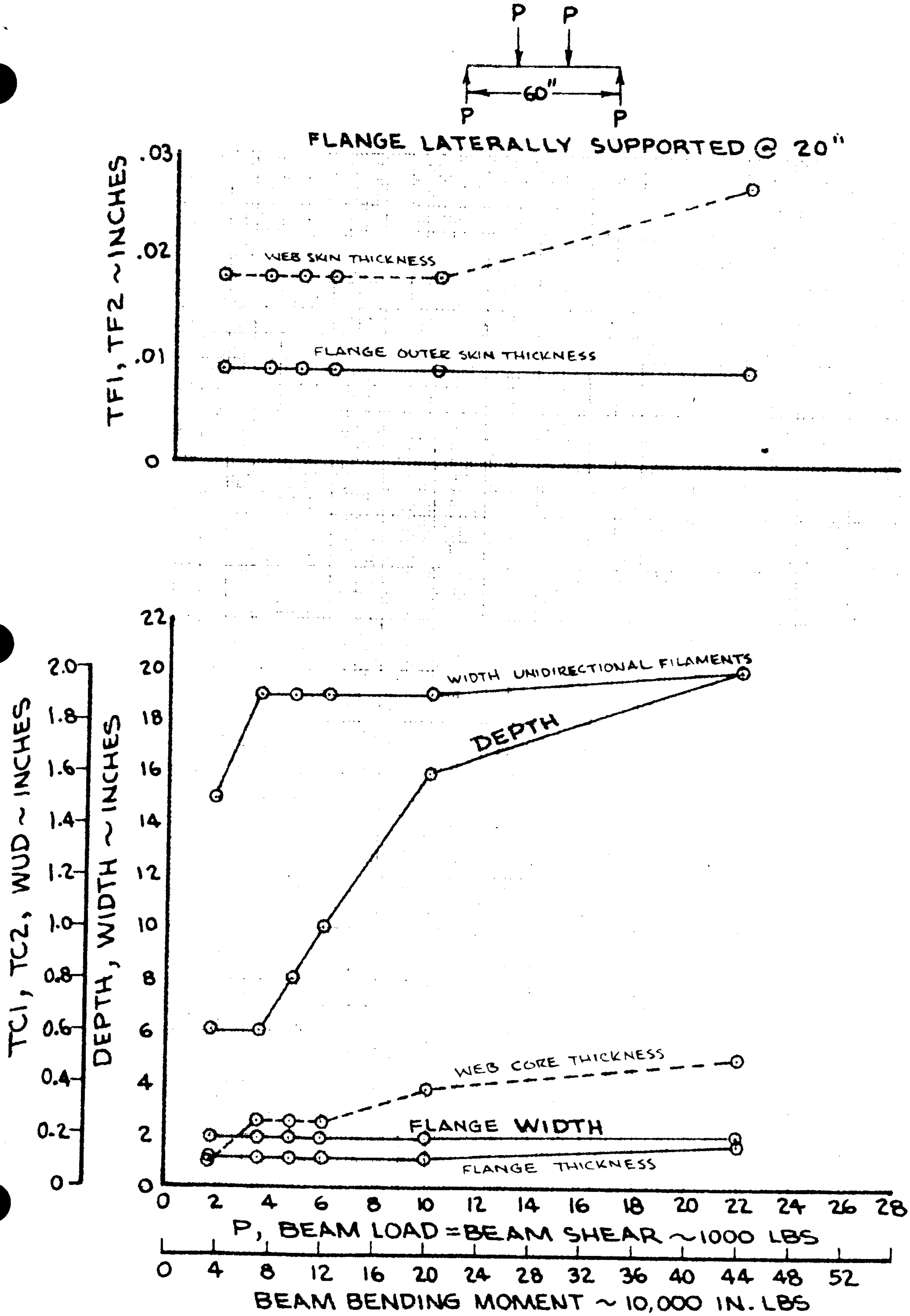
TITLE

BEAM WEIGHT COMPARISON
FIBERGLASS & ALUMINUM

MODEL

BOEING NO FIGURE 9

REV LTR



FIBERGLASS BEAM ~ SPAN = 60"

FIGURE 10

at loading points and at the ends. The aluminum loading brackets have been provided with holes for attachment of the lateral bracing. The calculated weight of the beam, not including the brackets, is 6.3 pounds.

The beam will be fabricated in a succession of molding and bonding steps. The web face skins (-4 on the drawing) will be laminated from 181 "S" glass cloth-E787 prepreg in an aluminum mold. All laminations will be placed in the exact position, the assembly will be vacuum bagged and cured under 50 psi autoclave pressure. Two separate layup and curing operations will be required to produce the face skins for one beam. The two flanges (-5) will be produced simultaneously by filling both sides of a channeled mold with the appropriate layers of glass cloth and 20 end prepreg roving. These flanges will also be vacuum bagged and cured under 50 psi autoclave pressure. The web face skins will be bonded to the phenolic honeycomb core and the flanges bonded to the face skins in one operation. A modified epoxy film adhesive will be used. The entire part will be vacuum bagged and autoclave pressure applied. A fixture will be used to hold all parts in alignment during cure, thus avoiding warpage. The final fabrication steps will be bonding the aluminum loading brackets in place with an epoxy-phenolic adhesive tape. Pairs of brackets are connected with bolts through the web to react the tension load due to eccentric loading. It was believed undesirable to carry this load through the adhesive bonds between brackets, web, and core material.

It is planned to fabricate two beams for testing. At least one beam will be instrumented during test to provide information on deflections at load points and midspan. Both lateral and vertical deflection will be measured at midspan. Strain gages will be installed on the tension flange at midspan and in one of the end bays on the shear web. The test will be conducted by increasing load until failure occurs.

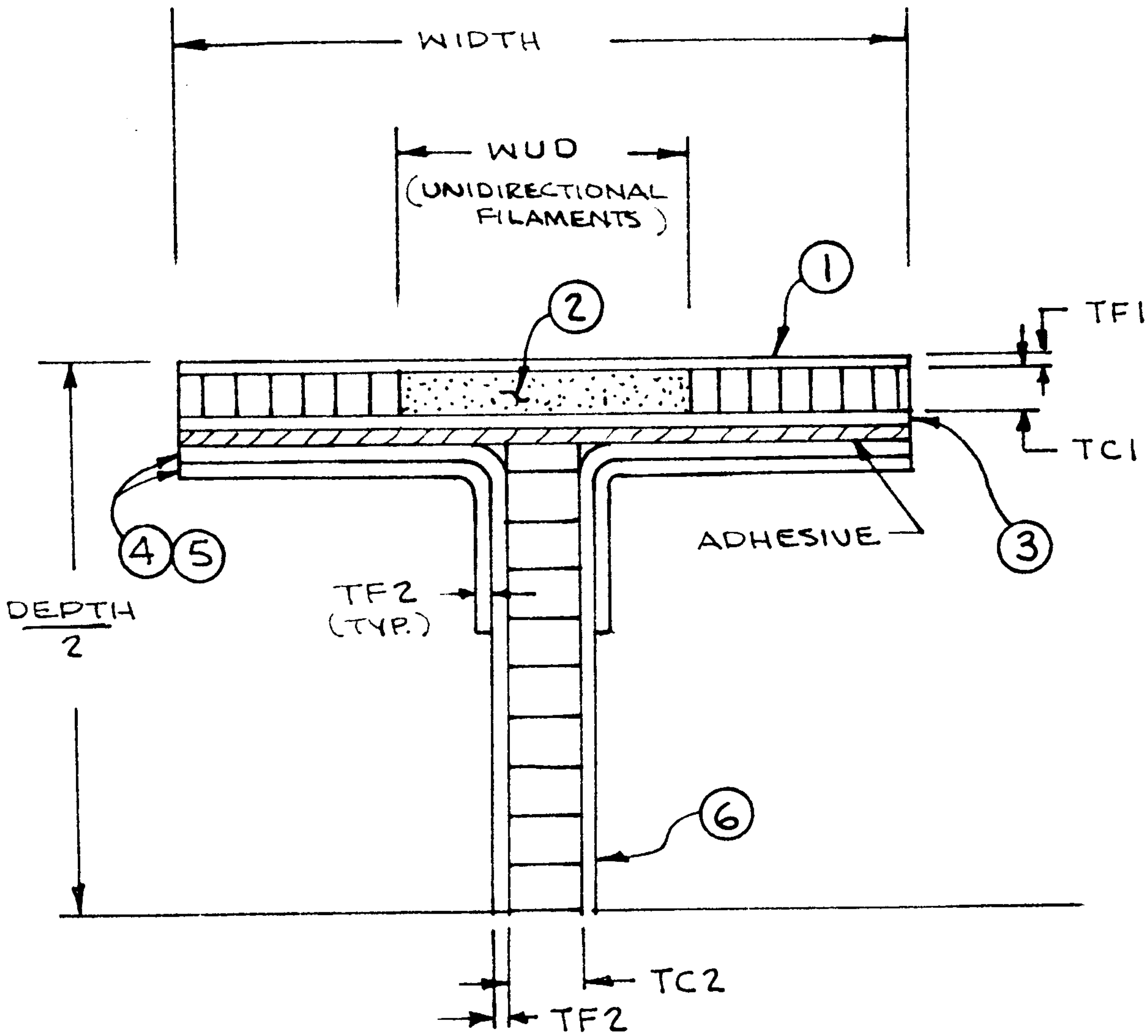
3.0 ANALYTICAL APPROACH

Beams

The configuration of the beam used in the computer optimization program was shown in the Second Quarterly Progress Report and is shown here as Figure 11 to aid in the discussion. This figure is representative of both the aluminum and fiberglass beams of this study. Figures 12 through 19 are plots showing the dimensions of all the elements for the most efficient (load capacity/weight) beams of fiberglass and aluminum construction in each span studied. Increases in flange and web skin thickness were accomplished in increments of .009 inches since this is approximately equivalent to one thickness of glass cloth.

In the shorter spans (20" and 40") the configuration of the flange is similar to that shown in Figure 11, i.e., a group of unidirectional filaments stabilized against lateral buckling with lightweight honeycomb core extensions on the outer edges. However, in the span selected for fabrication (60 inches) the most efficient flange configuration was one that used a solid group of unidirectional filaments.

Figures 20 through 23 are plots of midspan deflection and stiffness for the optimum aluminum and fiberglass beams with the element geometry described by Figures 12 through 19 respectively. It should be remembered that the optimum beam for a particular span and load was selected on the basis of minimum weight, without consideration for deflection or the physical dimensions of the cross section, therefore, the deflection plots are not necessarily smooth curves. Figure 22, for example, shows that the deflection of the optimum 60 inch fiberglass beam increases abruptly with increased load capacity and then drops equally abruptly, leveling off at the higher loads. An examination of the "depth", "width", "WUD" and "TCI" curves of Figure 16 indicates possible reasons why this has happened. As load has increased from 1300 to 3600 pounds, the beam depth and flange thickness have remained constant, while the width of unidirectional



BEAM ELEMENTS

FIGURE 11

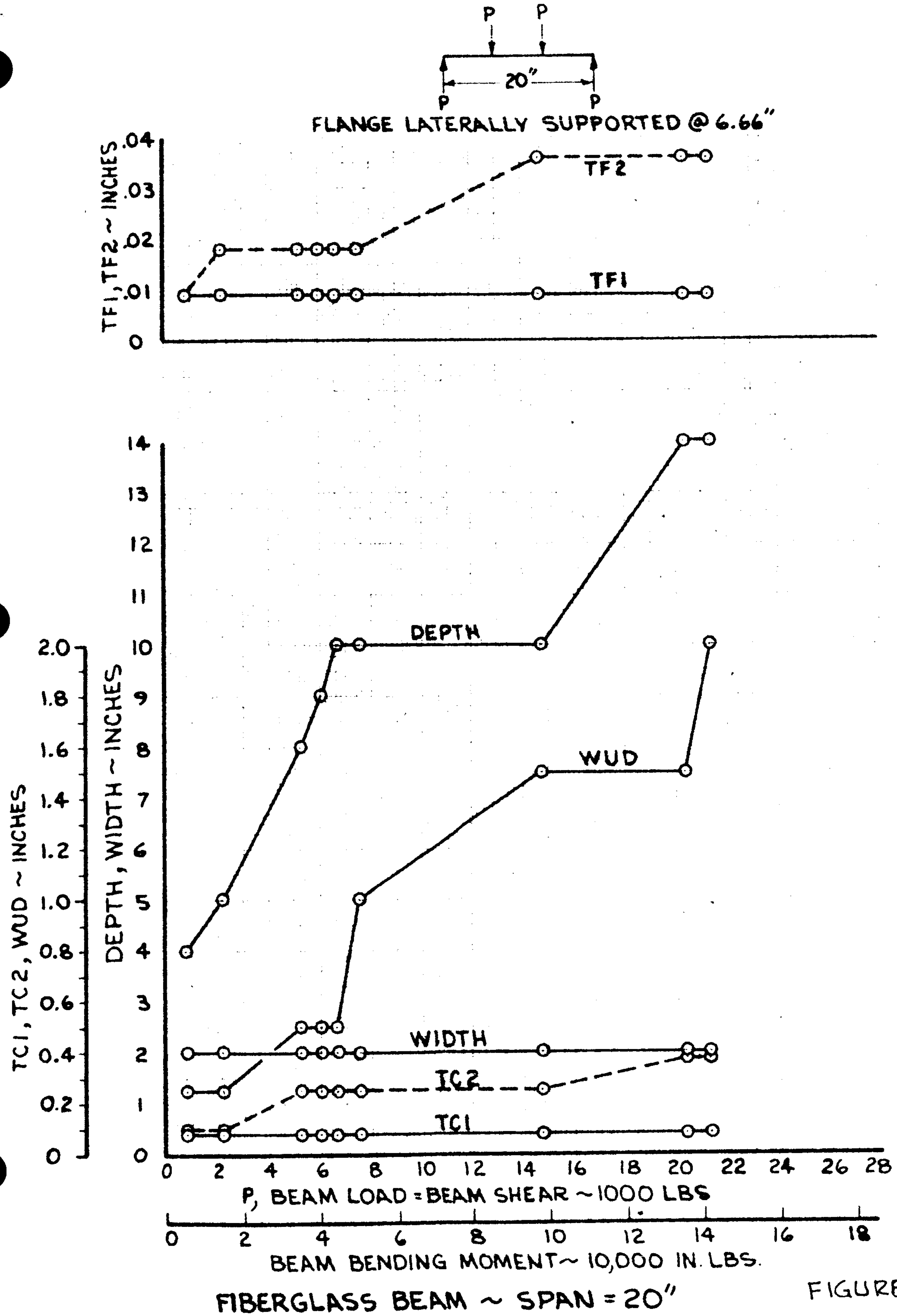

P
P
20"
P
P
FLANGE LATERALLY SUPPORTED @ 6.66"
TF1, TF2 ~ INCHES
.04
.03
.02
.01
0
TF2
TF1
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
DEPTH, WIDTH ~ INCHES
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
TC1, TC2, WUD ~ INCHES
DEPTH
WUD
WIDTH
TC2
TC1
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28
P, BEAM LOAD = BEAM SHEAR ~ 1000 LBS
0 2 4 6 8 10 12 14 16 18
BEAM BENDING MOMENT ~ 10,000 IN. LBS.
FIBERGLASS BEAM ~ SPAN = 20"

FIGURE 12

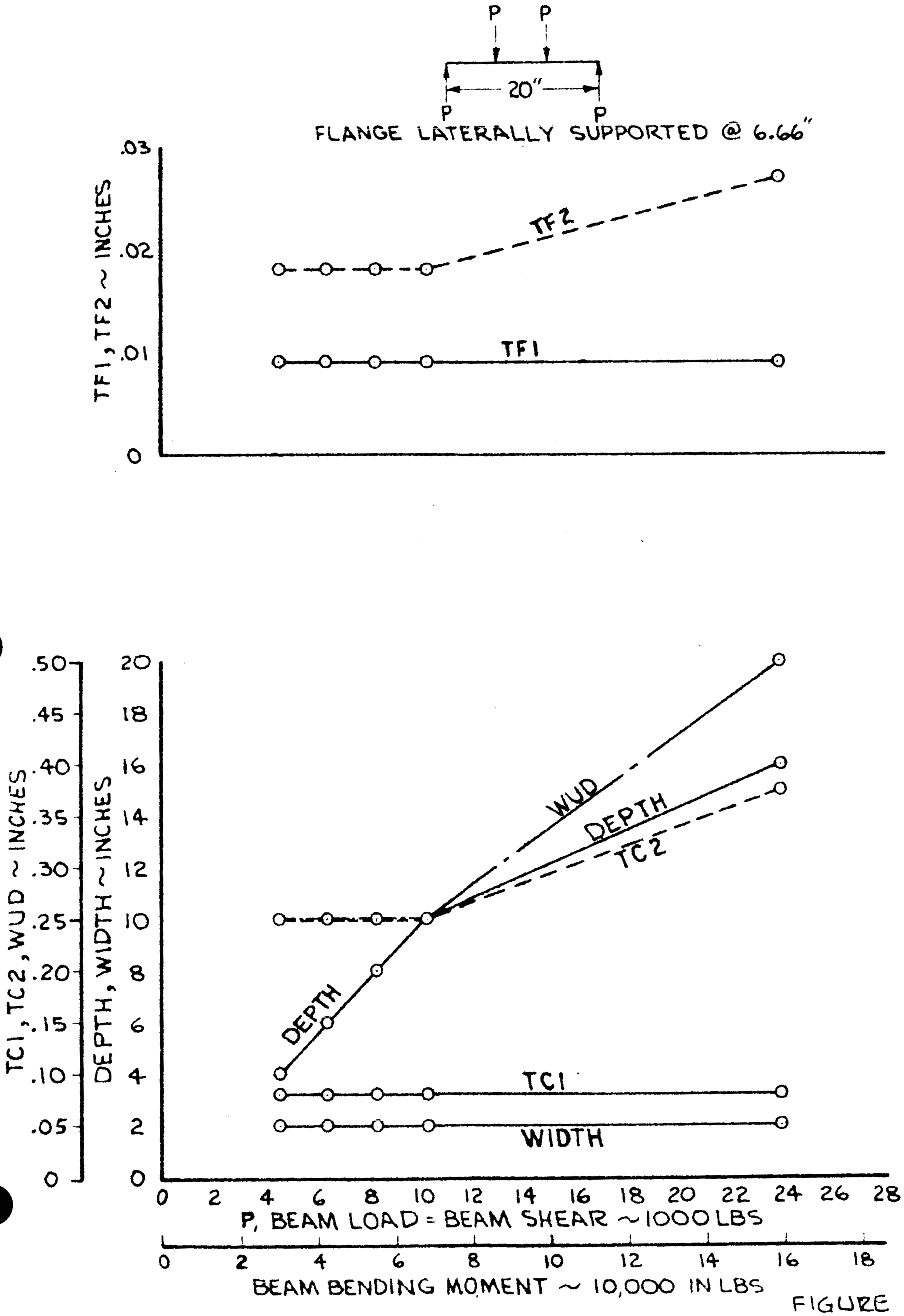


FIGURE 13

ALUMINUM BEAM ~ SPAN = 20"

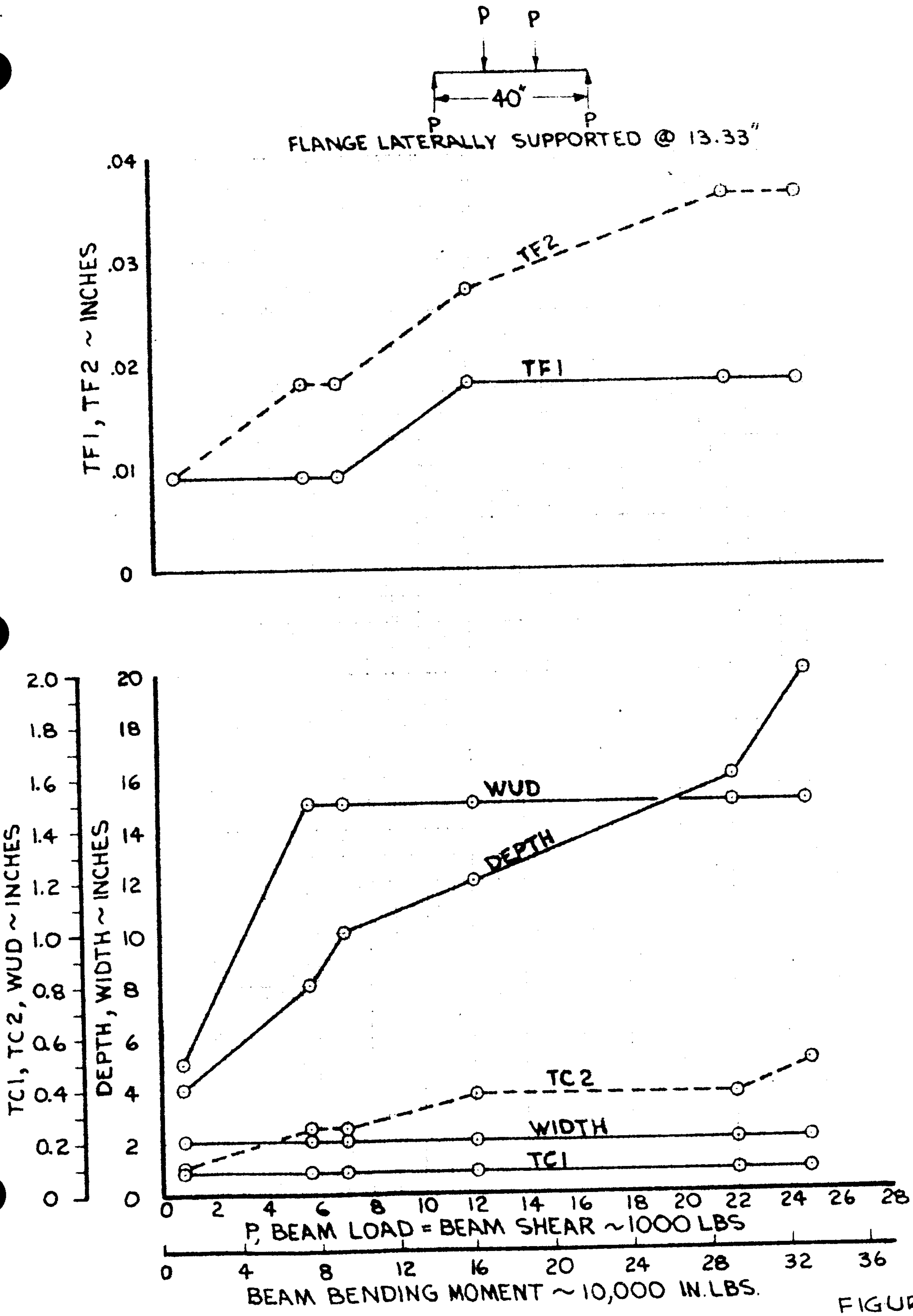
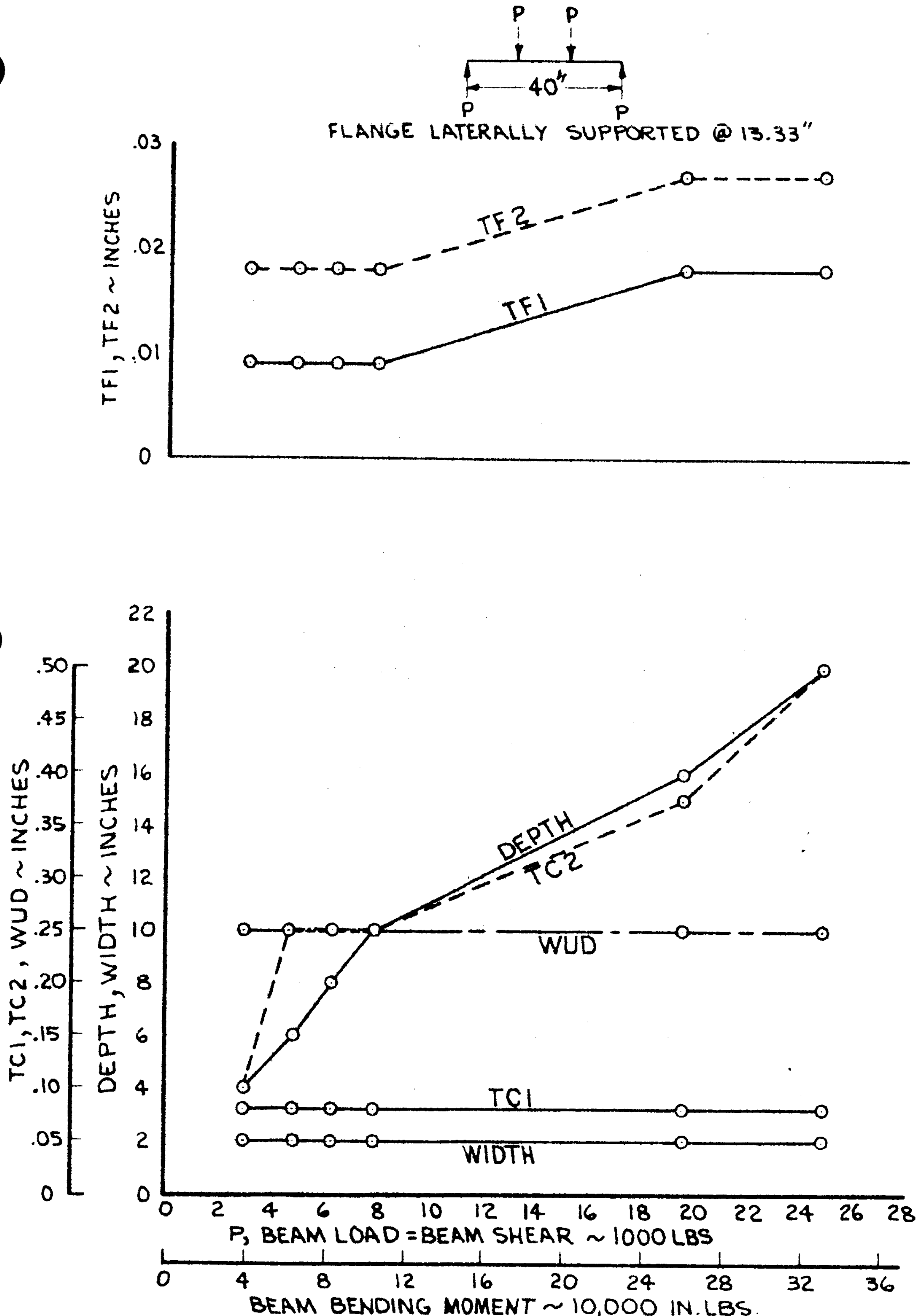


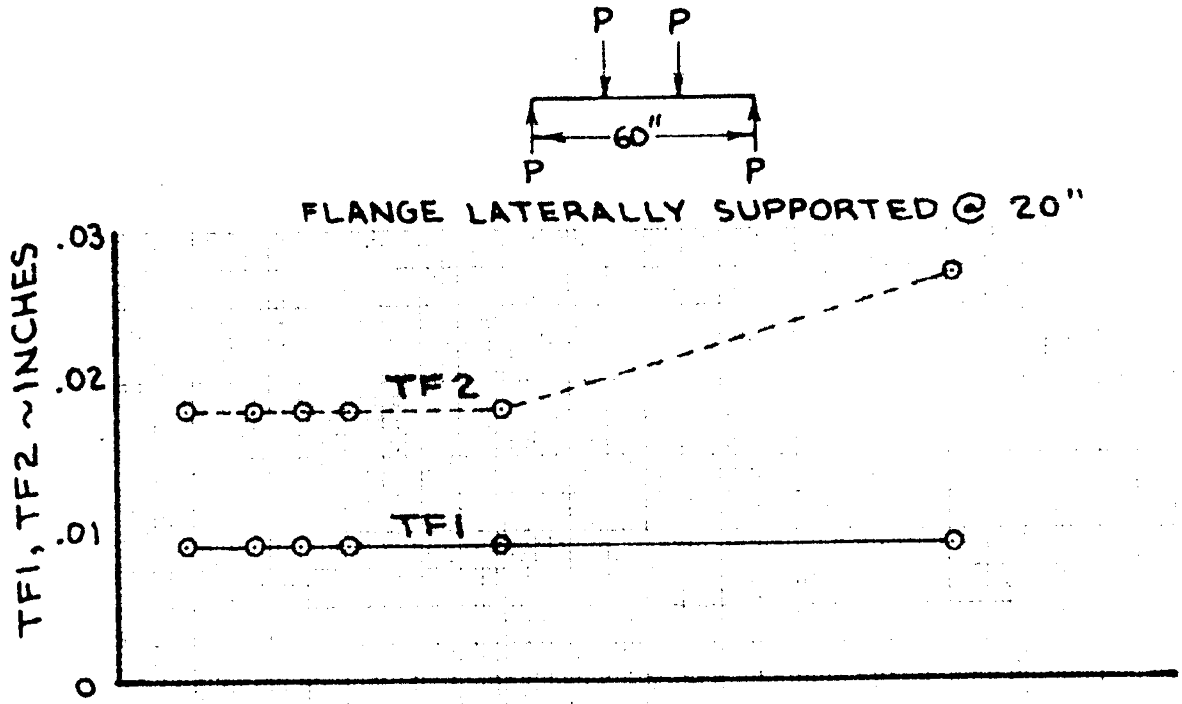
FIGURE 14

FIBERGLASS BEAM ~ SPAN = 40"



ALUMINUM BEAM ~ SPAN = 40"

FIGURE 15



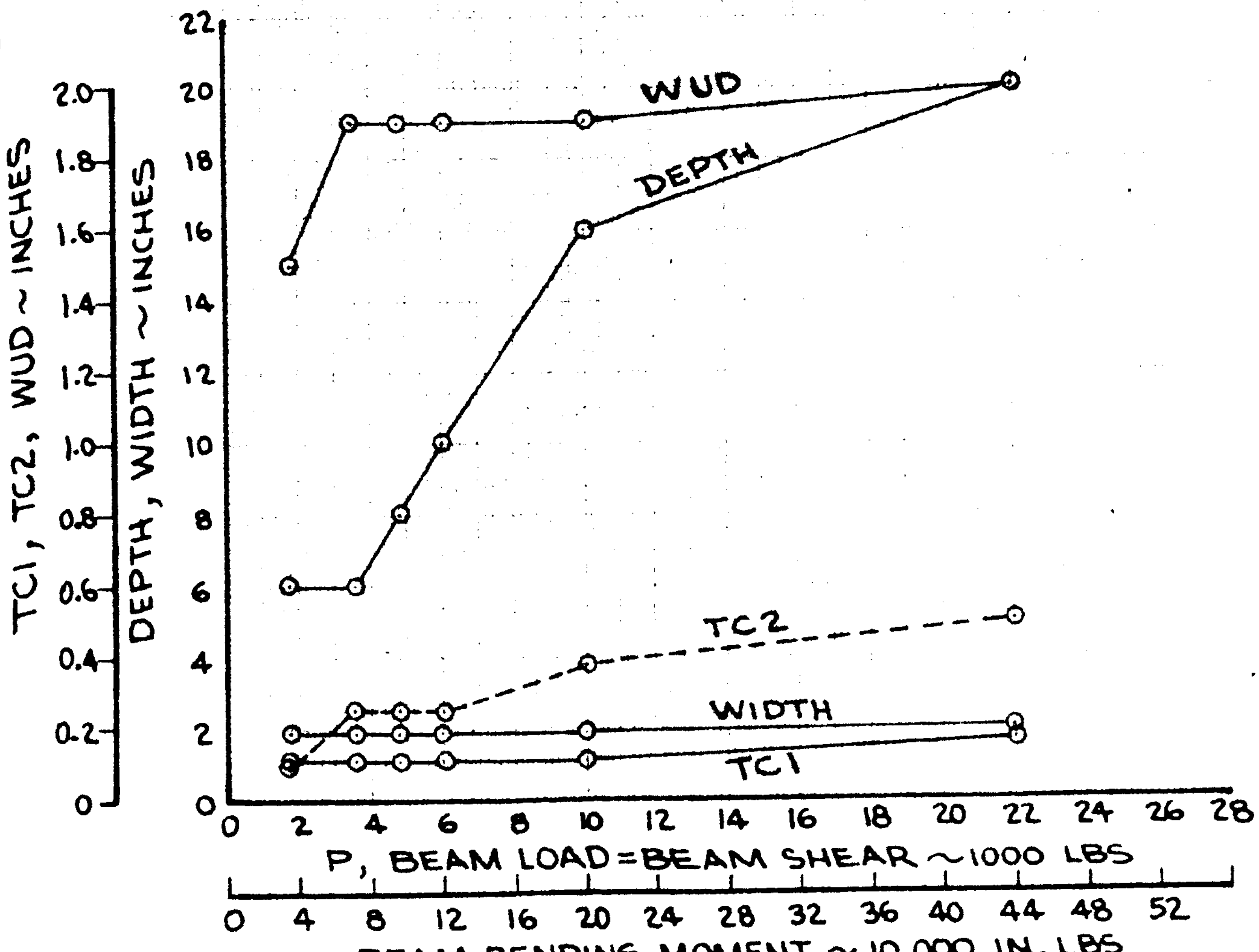


FIGURE 16

FIBERGLASS BEAM ~ SPAN = 60"

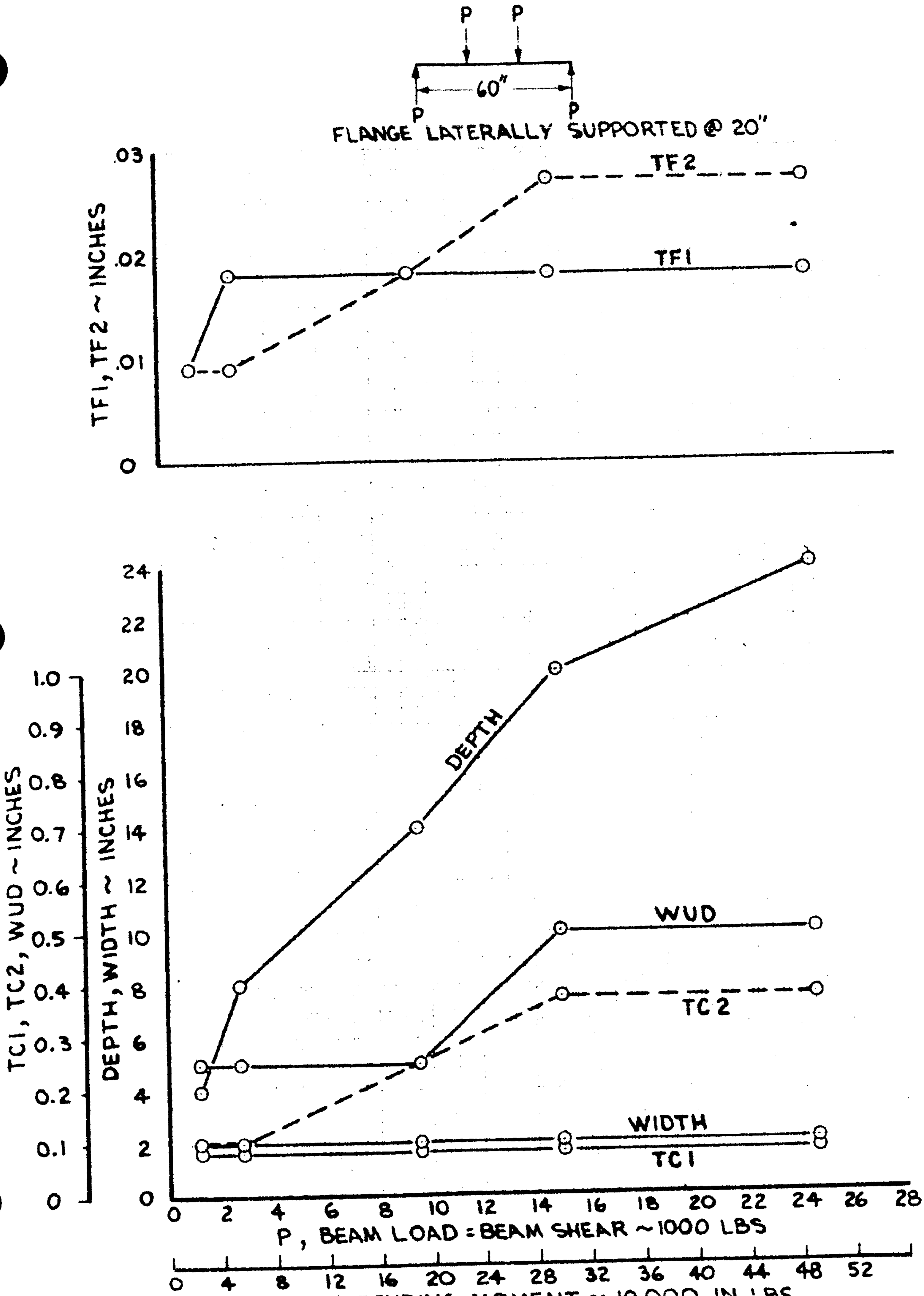


FIGURE 17

ALUMINUM BEAM ~ SPAN = 60"

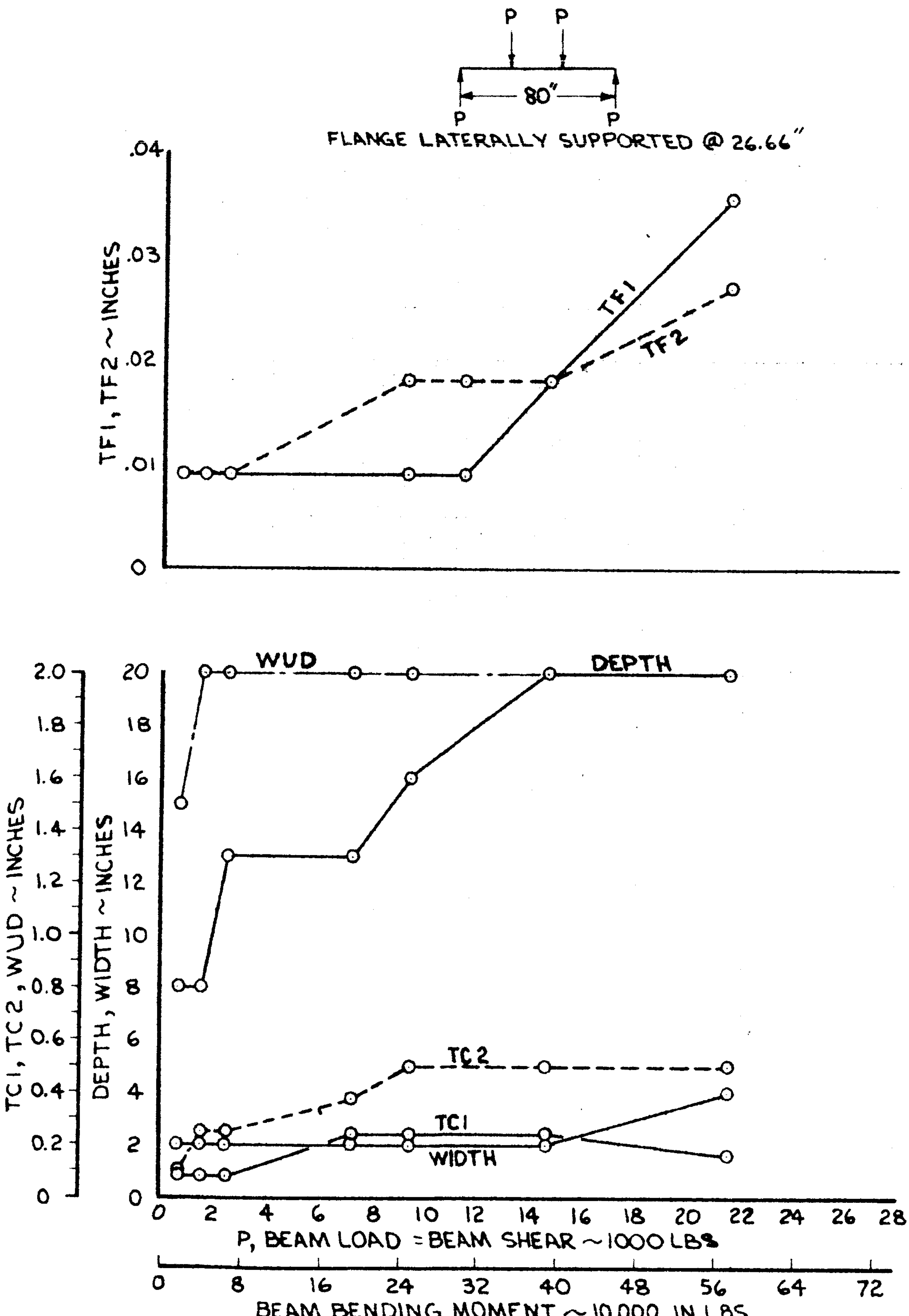


FIGURE 18

FIBERGLASS BEAM ~ SPAN = 80"

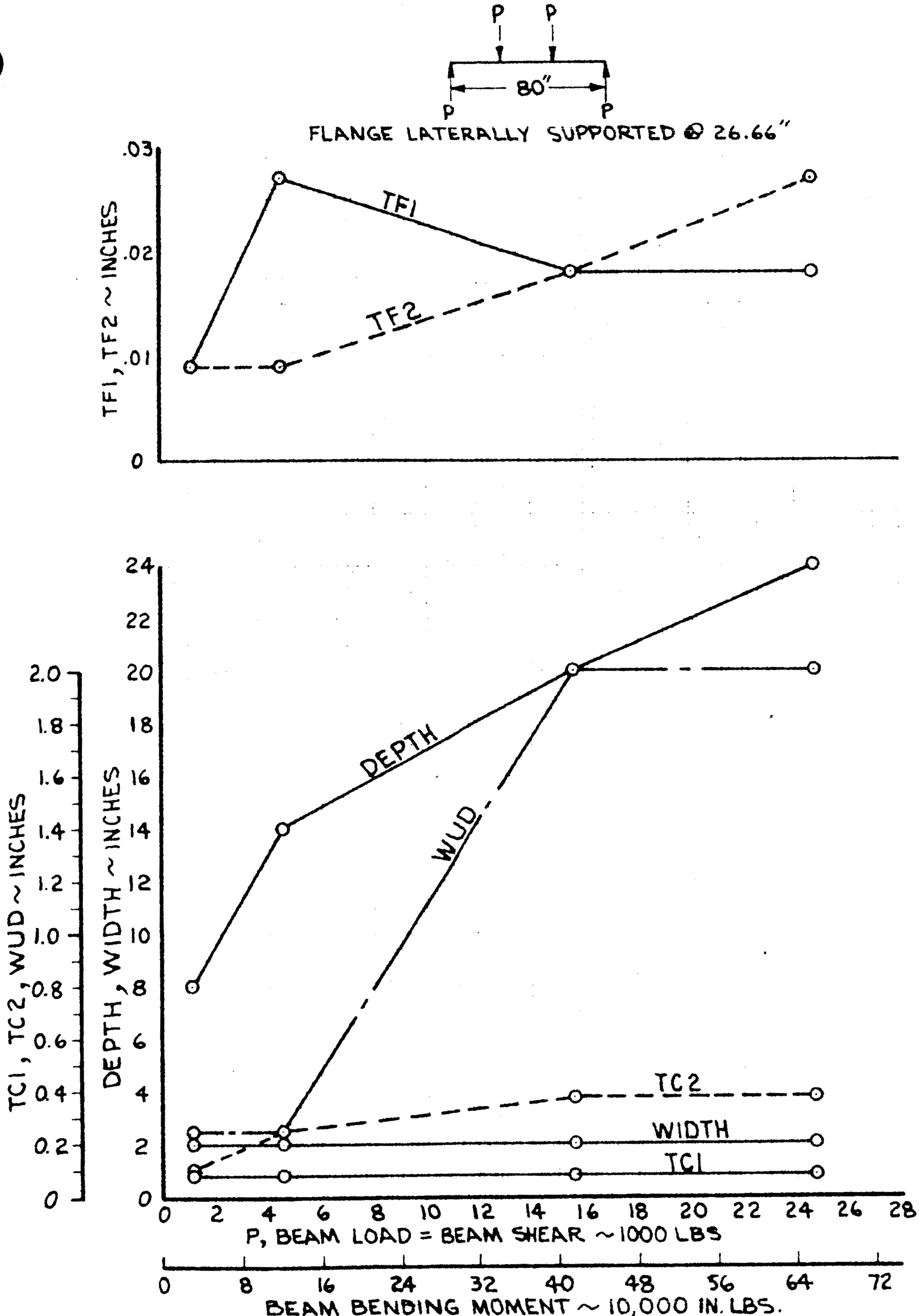


FIGURE 19

ALUMINUM BEAM ~ SPAN = 80"

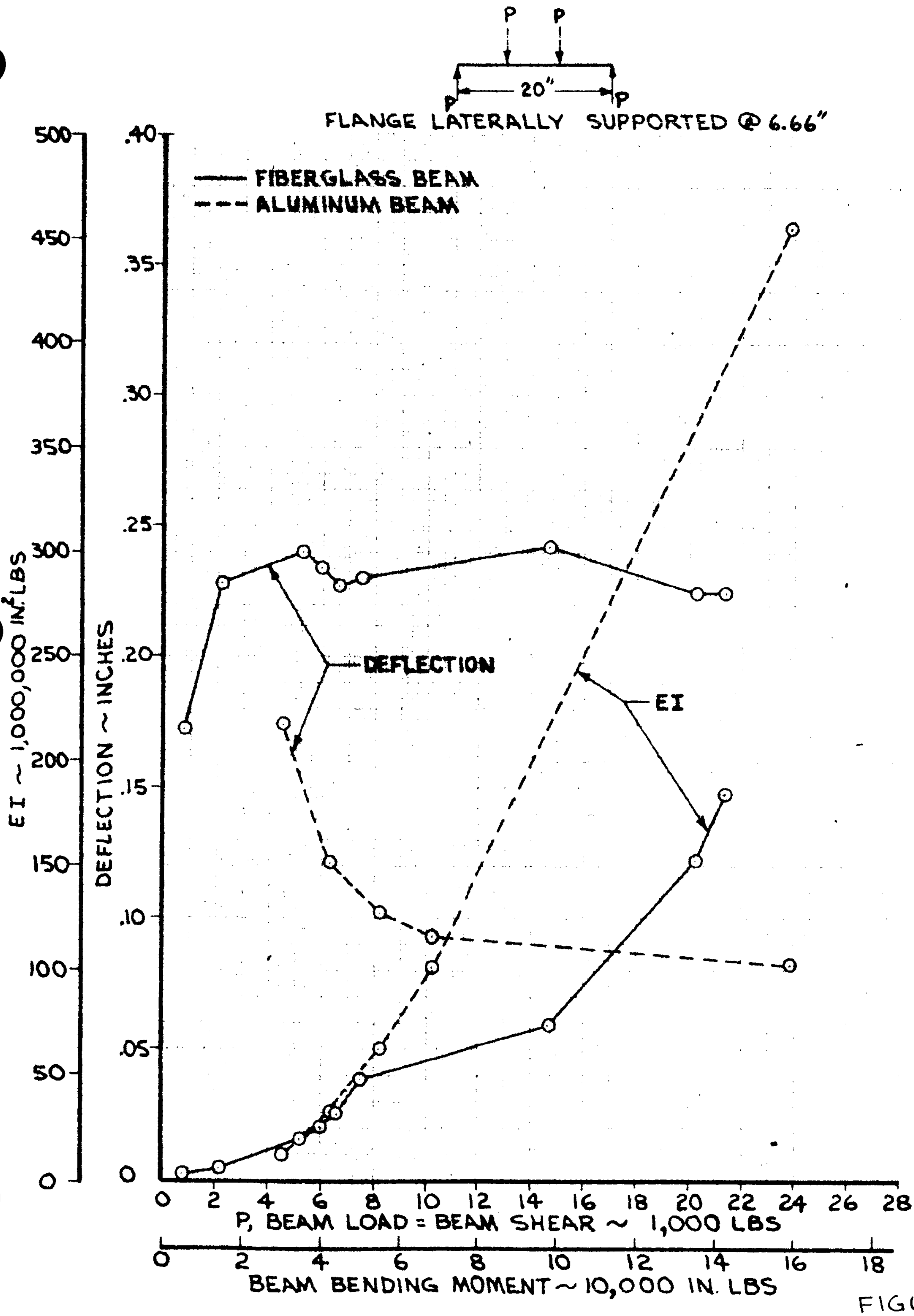


FIGURE 20

FIBERGLASS AND ALUMINUM BEAMS ~ SPAN = 20"

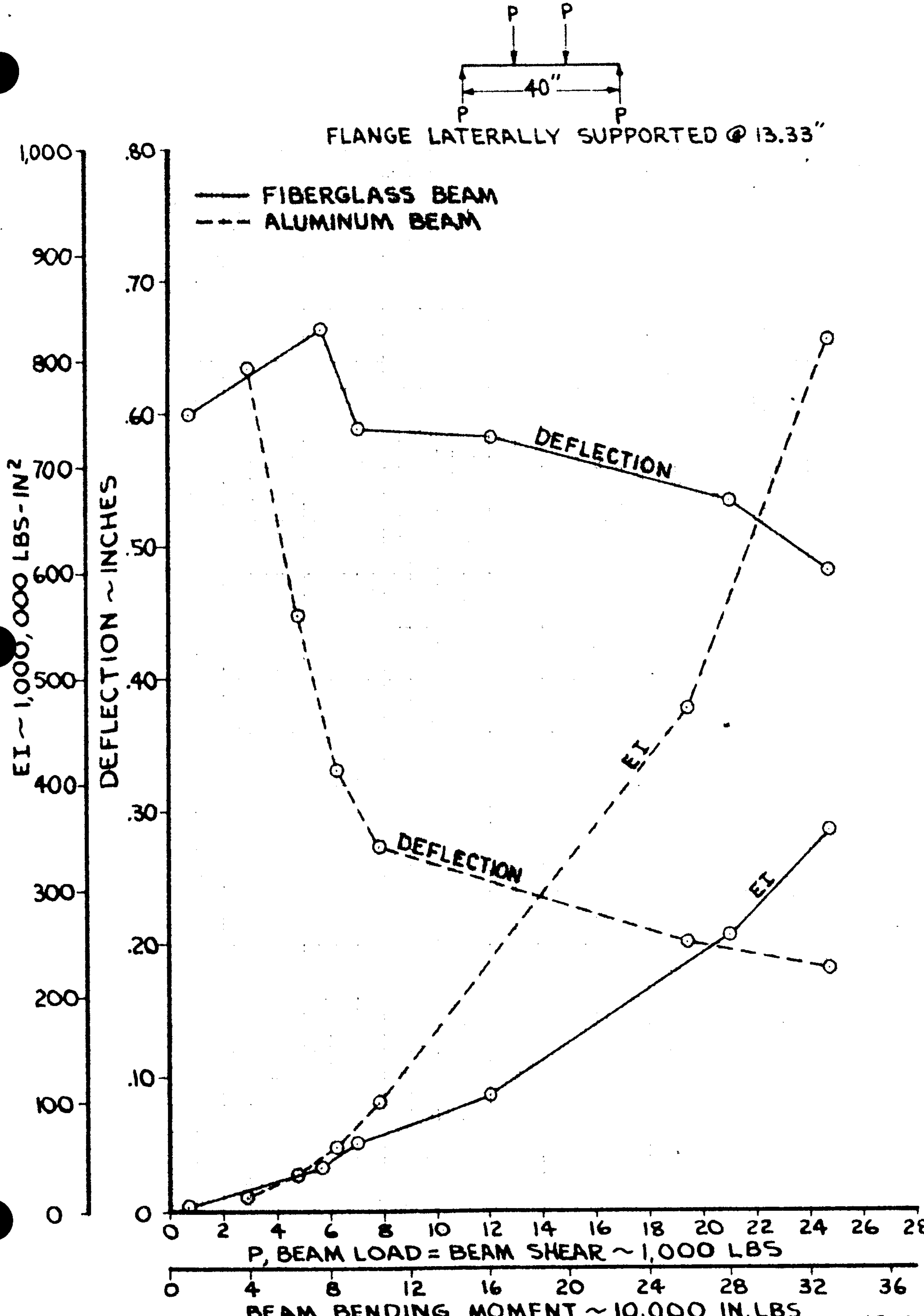


FIGURE 21

FIBERGLASS AND ALUMINUM BEAMS ~ SPAN = 40"

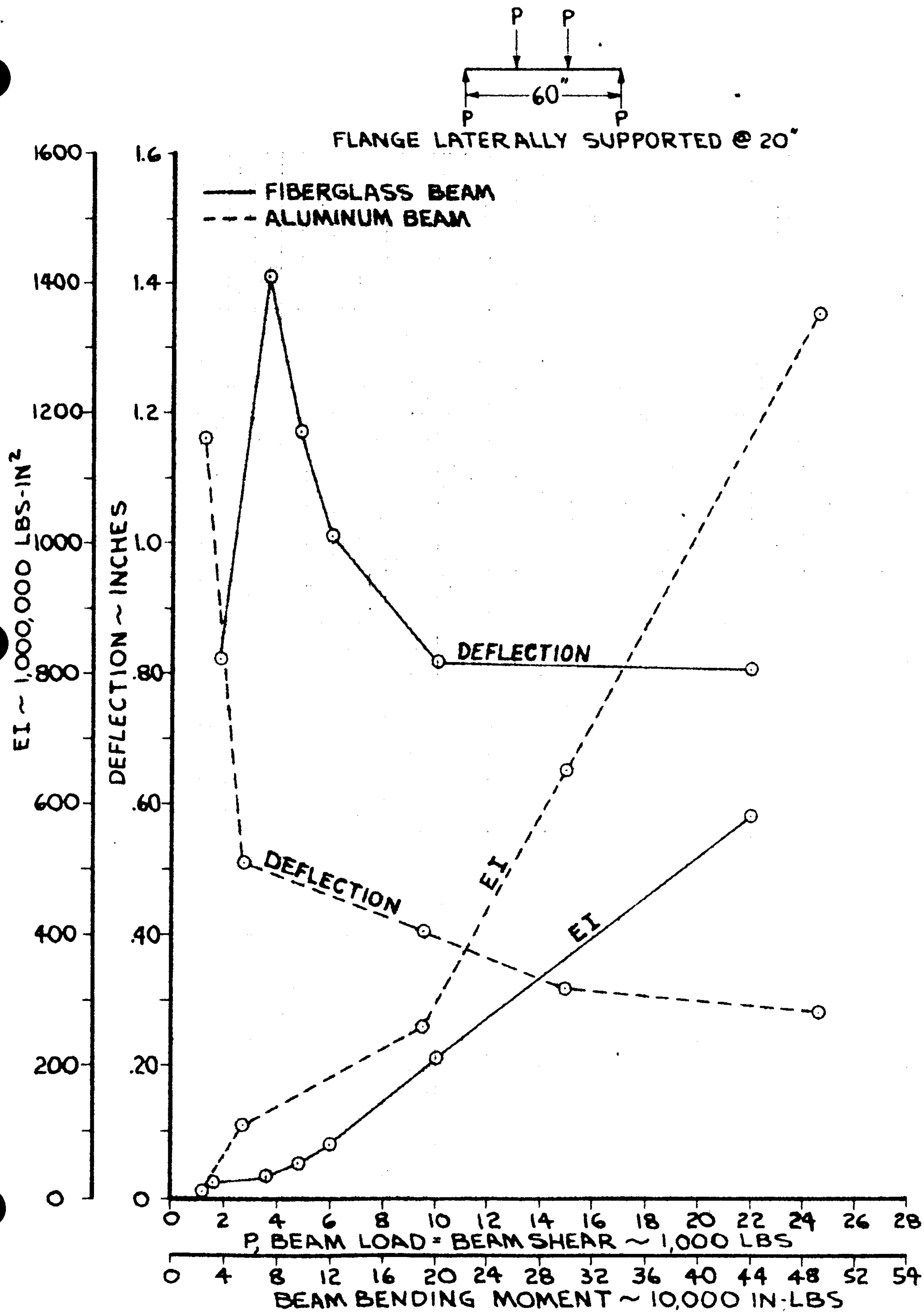
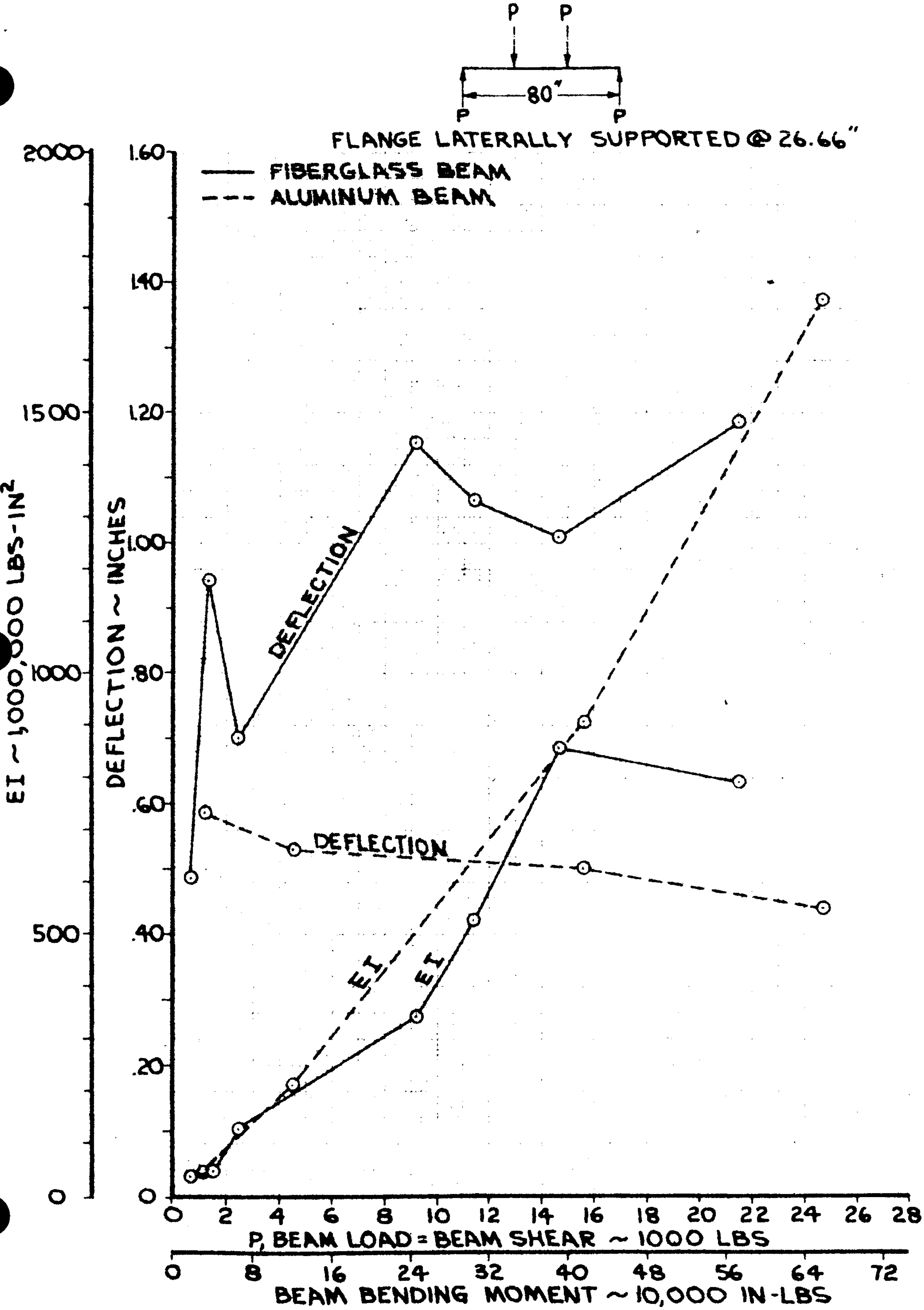


FIGURE 22

FIBERGLASS AND ALUMINUM BEAMS ~ SPAN = 60"



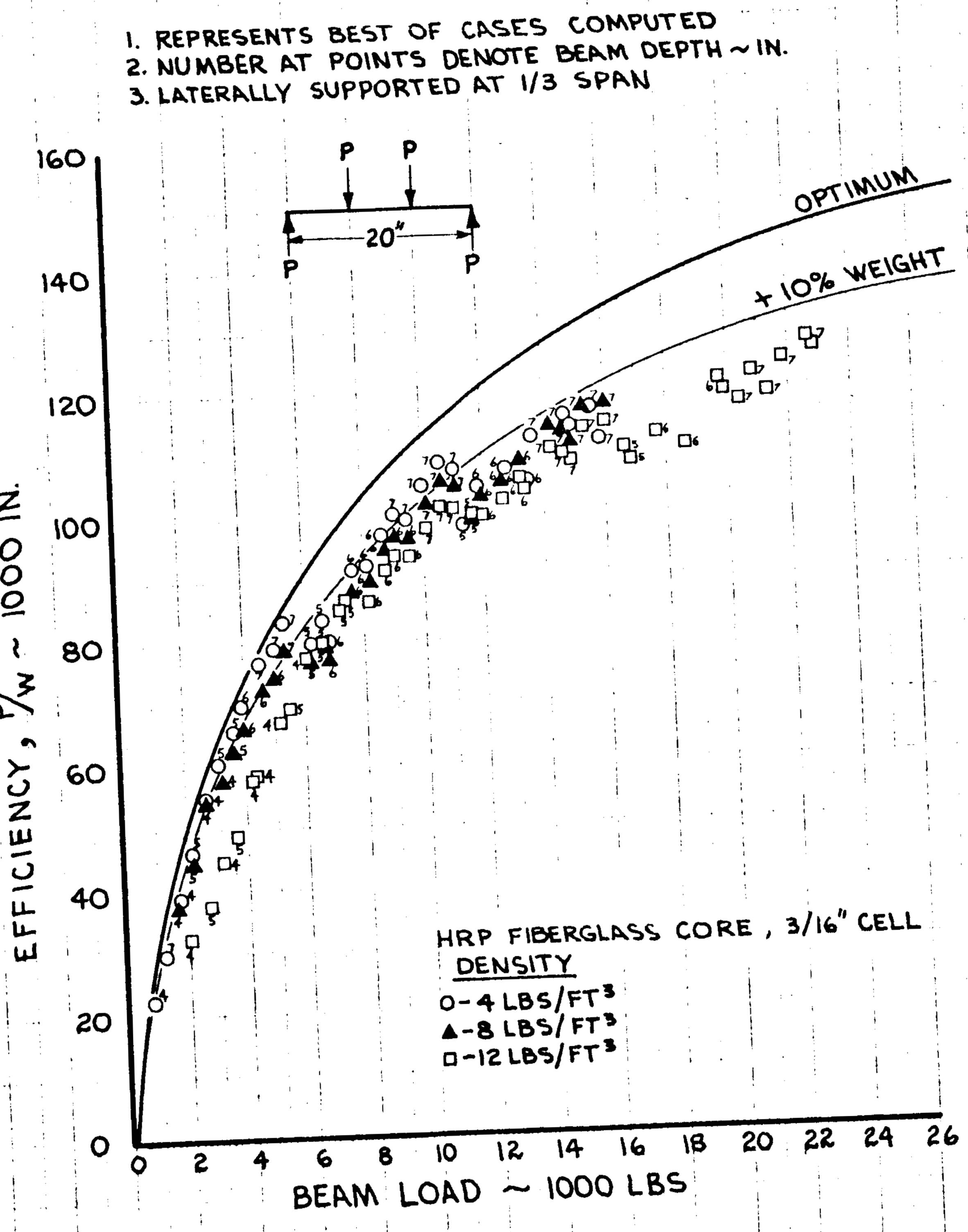
FIBERGLASS AND ALUMINUM BEAMS ~ SPAN = 80"

FIGURE 23

filaments has increased. This increase in the number of unidirectional filaments may well account for the increased load capacity; however, the deflection is apparently more closely related to the depth and flange thickness of the beam giving a large increase in deflection with increasing load. Beyond 3600 pounds load, the beam depth increases and the deflection becomes less. It is possible that these wide program excursions would not have occurred if more cases had been included in the computer analysis.

During the fiberglass beam optimization study an analysis of the effect of honeycomb **core** density on beam efficiency was made. The results of this study are shown in Figure **24**. The "optimum" curve drawn on this graph is taken from Figure 12 of the Second Quarterly Progress Report and was established from a large quantity of points including beam depths greater than those considered in Figure **24.** Although the entire range of beam depths is not shown in Figure **24,** the trend towards higher efficiency with the low density core is obvious. The heavier core, however, allowed shallower depths with an attendant increase in web skin thickness, the net result being an increase in weight. Increased deflection also accompanies the shallower beams. The 3/16 inch cell, 4 lb/ft^3 phenolic honeycomb core was selected for beam fabrication.

In the Second Quarterly Report, twelve possible modes of beam failure were identified (reference: Figure 10). Of these twelve, nine constitute possible failure modes for the 60 inch long by 12 inch deep beam shown in Figure 9. Three possible modes were eliminated when a solid unidirectional filament flange was selected instead of a small group of unidirectional filaments stabilized on the edges by honeycomb core and face skins. The computer program has determined the maximum load "P" this beam will support for each of the failure modes when loaded as shown in the sketch. The maximum loads for each failure mode are tabulated below:



	INITIALS	DATE	REV BY INITIAL	DATE	TITLE	MODEL
CALC					COMPARISON OF VARIOUS CORE DENSITIES FIBERGLASS BEAM ~ SPAN = 20"	
CHECK						
APPD.						
APPD.						

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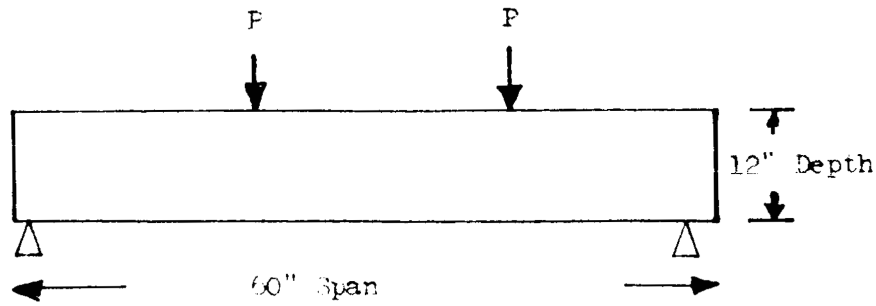
REV LTR

BOEING NO FIGURE 24

SH.



Mode	Beam Load ~ P (Pounds)
Maximum Bending Strain	18,719
Adhesive shear - outer cloth layer on flange to unidirectional filaments	1,358,047
Adhesive shear - unidirectional filaments to inner cloth layer on flange	40,603
Web edgewise shear	11,122
General web buckling	10,196
Web intracell buckling	8,541
Web face wrinkling	9,038
Flange crippling	9,247
Flange lateral instability	8,514

From this tabulation it can be seen that the beam should fail by either web intracell buckling or flange lateral instability at a concentrated load of approximately 8500 pounds, or a total beam load of 17,000 pounds.

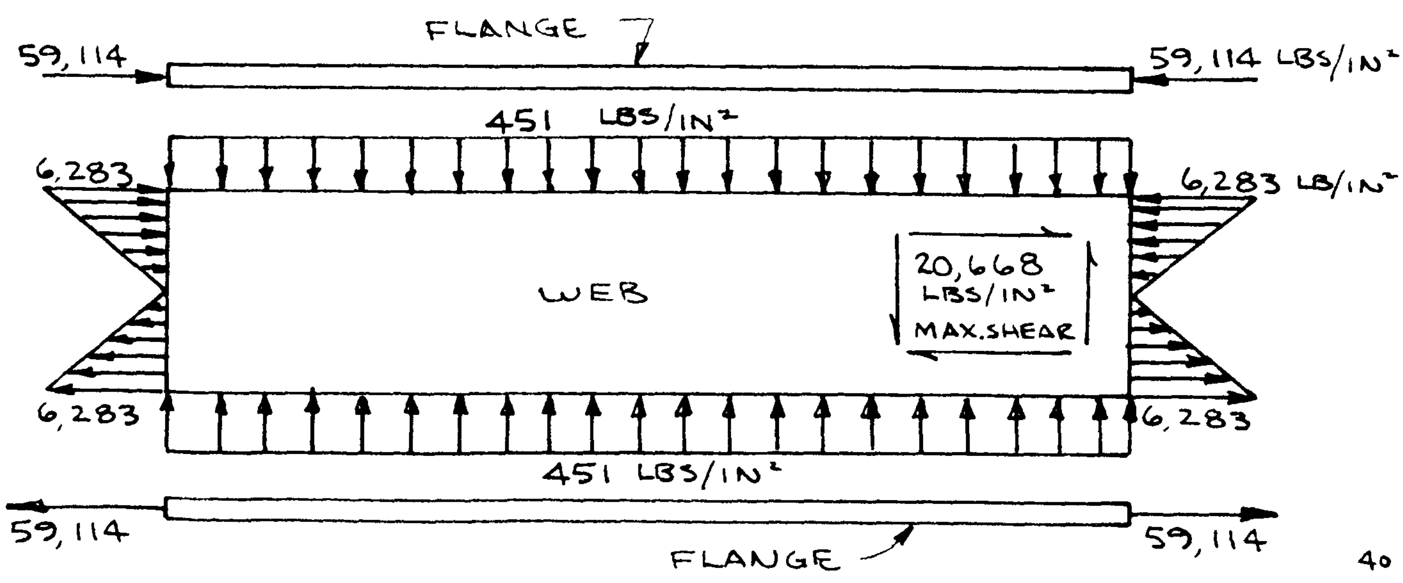
Referring to Figure 11 the actual and allowable stresses in each of the beam elements at P = 8500 pounds are as follows:

Element	Compressive or Tensile Stress ~ psi	Allowable Stress ~ psi	Type of Failure
#1	22,291	* 22,291 (55,000 tension 58,225 compression)	Lateral instability
#2	59,114	* 59,114 (252,463 tension 131,188 compression)	Lateral instability
#3	21,945	* 21,945 (55,000 tension 58,225 compression)	Lateral instability
#4 & 5	6,931	26,782 compression 14,196 tension	
#6	6,283 (flexure)	* 15,441 (14,196 tension 26,782 compression)	Intracell buckling
	451 (transverse compression)	* 9,022 (26,782 compression)	General web buckling

* Allowable stresses shown are the maximum that can be developed prior to failure by elastic instability. The numbers in parenthesis are the maximum allowable stresses possible if failure did not occur by instability.

Elements	Shear Stress ~ psi	Allowable Stress ~ psi
1 to 2	10	1600
2 to 3	335	1600
[illegible]	20,668	27,000

A sketch of the stress distribution in the fiberglass beam is shown below:



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1. Program for the evaluation of Structural Reinforced Plastic Materials at Cryogenic Temperatures, L. W. Toth, et al, NASA/MSFC Contract NAS 8-11070, Goodyear Report GER 12792.

2. D2-22259, "Glass Reinforcement Tensile Test Method", N. Pirzadeh and P. Kennedy, The Boeing Company, March 19, 1963.

3. QCDR 2-2901, "New Test Method for Multiple-Strand Fiberglass Roving", N. Pirzadeh, The Boeing Company, Nov. 14, 1963.

4. "Thermal Conductivity of Reinforced Plastics at Cryogenic Temperatures", J. Hertz and J. Haskins, Contract AF 33(657)-9160, General Dynamics/Astronautics.